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# Oral Presentations

## Common Keynotes

### SEISMOLOGICAL INFORMATION FOR DISPLACEMENT-BASED DESIGN - A STRUCTURAL ENGINEER'S WISH LIST – K1-A

*Priestley Nigel, "Rose School" c/o EUCENTRE, Pavia, Italy*

With conventional force-based seismic design, the most important information for the structural engineer has been the effective peak ground acceleration. This number is comparatively insignificant in displacement-based or performance-based seismic design, where the key data are peak spectral response displacement, and the "corner" period at which this occurs. There appears to be a disagreement between seismologists on opposite sides of the Atlantic about these data, which the structural engineer views with concern, since ductile structural response will often be in this region of the corner period.

Other areas needing clarification include the issue of how to develop accelerograms for time-history analysis compatible with the design seismicity using an acceptably small number of accelerograms, and how to reconcile the statistical nature of seismicity characterization with the structural engineer's preference for deterministic analysis. There is some evidence that a consequence of this is invalid averaging of response characteristics by structural engineers.

These and other points will be explored in the presentation.

### EARTHQUAKE DYNAMICS AND THE PREDICTION OF STRONG GROUND MOTION – K1-B

*Madariaga Raul, Laboratoire de Géologie, Ecole Normale Supérieure, Paris, France*

A large number of earthquakes have been modeled in detail using seismological, geological and geodetical informations. Several common traits have been found for earthquakes kinematics at relatively low frequencies of up to 0.3 Hz.

All earthquales appear complex at these wavelength and propagate with rupture velocities close to about 80% of the shear wave speed. From these kinematic inversions it has been possible to derive dynamic faulting parameters like the energy release rate, some details of the friction law that controls rupture propagation, and the magnitude of shear stresses in the crust .

These results may now be extended to the higher frequencies of interest to earthquake engineering by means of dynamic rupture propagation, where rupture is simulated in a fault system loaded by tectonic stresses. We have shown that these models have many features of actual earthquakes, including an w -2 spectral behaviour at frequencies higher than the corner frequency. In this talk I will review the main results obtained so far and the new avenues of research that have been opened thanks to new earthquake data and the ability to simulate increasingly complex and realistic ruptures in a computer.

### SEISMIC HAZARD ASSESSMENT: PROBLEMS WITH CURRENT PRACTICE AND FUTURE DEVELOPMENTS – K2

*Abrahmson Norman, Pacific Gas & Electric Company, San Francisco, CA, United States*

This paper addresses issues with current practice in seismic hazard analysis and gives some recommendations for improvements. A review of probabilistic and deterministic approaches is given. The remainder of the paper is focused on PSHA. There continue to be hazard studies that do not properly treat the ground motion variability, leading to systematic underestimations of the hazard. Next, some of the short-comings in current PSHA practice that can be improved without major revisions to the overall methodology are discussed. These include selecting the bin size for the deaggregation, use of Uniform Hazard Spectra, estimation of scenario spectra, estimation of epistemic uncertainty, degree of spatial smoothing of seismicity, and the use of a strict lower bound magnitude. Finally, the future directions of PHSA are addressed. These include incorporating site-specific site response into PSHA and taking project specific structure response into account in conducting PHSA.

### SITE EFFECT EVALUATION IN AREAS OF LOW SEISMICITY – K3

*Fäh Donat, Swiss Seismological Service ETH-Hoenggerberg, Zurich, Switzerland*

Numerous methods have been developed to evaluate site-effects during strong earthquakes. In areas of low to moderate seismicity no strong motion recordings are available and site effect studies have to rely on weak motion records or numerical modelling. Numerical modelling requires good knowledge of the geophysical structure, and needs cheap and fast methods to measure the important physical parameters. Ambient vibration techniques have therefore become very important: they provide information on the eigen-vibrations of the geological structure and estimates of S-wave-velocities as a function of depth. The presentation will give examples of the work done in Switzerland with focus on site-specific hazard studies, on site characterization of the seismic stations, and on possible applications for building codes.

### URBAN EARTHQUAKE RAPID RESPONSE AND EARLY WARNING SYSTEMS – K4

*Erdik Mustafa, Kandilli Observatory and Earthquake Research Institute - Bogazici University, Istanbul, Turkey*

Technological advances in seismic instrumentation and telecommunication permit the implementation of real-time rapid response and early warning systems.

During large earthquakes, such systems are capable of providing from a few seconds to a few tens of seconds of warning before the arrival of strong ground shaking and enable a quick reports about the damage estimates to determine where emergency response is most needed.

A review of the systems current in operation around the world will be given.

A case study and examples will be provided from Istanbul Earthquake Rapid Response and Early Warning System, where 100 dedicated strong motion stations located throughout the city to constitute a network that will enable rapid shake map and damage assessment after a damaging earthquake and 10 strong motion stations are sited in proximity to the Main Marmara Fault for the generation of early warning information.

### NEW STRATEGY FOR EARTHQUAKE RISK MANAGEMENT – K5

*Okazaki Kenji, National Graduate Institute for Policy Studies (GRIPS), Tokyo, Japan*

In earthquake disasters, most of deaths are attributed to vulnerable buildings. It is therefore indispensable to make existing houses/buildings safer, to reduce the victims and damage resulting from earthquakes. After Kobe Earthquake in 1995, various projects and research studies have been conducted and new policies have been made in Japan in effort to mitigate seismic disasters. However, a large number of vulnerable buildings still exist. Vulnerable adobe and masonry houses, which are commonly seen throughout the developing world, also exist in a huge number, and are being reproduced, although we have the technologies to reduce the impact of earthquakes and know what kind of building regulations are necessary. Vulnerable houses/buildings can be retrofitted only by owners themselves. It is thus essential to motivate and empower people through co-learning and risk communication among all the stakeholders so that they can understand the problems and can take appropriate actions.

## Engineering Keynotes

### NEW GENERATION OF STRUCTURAL CONCRETE SYSTEMS FOR SEISMIC RESISTANCE – K6

*Restrepo José I., Structural Engineering - University of California, San Diego, United States*

The impact and cost of the consequences of damage caused by earthquakes worldwide during the past two decades have raised serious questions of whether current building seismic design philosophies are satisfying the needs of modern society. The rapid advance in technology has meant that often, in many countries, the cost of equipment, of stock and the loss of business operation in the aftermath of a moderately or strong earthquake are higher than that of the building itself. For this reason it seems obvious that there is need to develop new structural systems that are designed for specific performance objectives and that are aimed specifically at minimizing seismically induced structural damage. The behavioural response characteristics and design of these systems are examined in this keynote lecture. In particular, the use of rocking wall systems and of systems incorporating high-performance materials will be discussed.

### ON SEISMIC DESIGN OF FOUNDATIONS – K7

*Gazetas George, National Technical University Athens, Greece*

The presentation will concentrate on methods of analysis of shallow, embedded, and deep foundations subjected to strong seismic shaking. Emphasis will be given on the practical significance of soil - foundation - structure interaction analysis. The role of foundation uplifting and soil plastification will be explored and illustrated through case histories. Issues related to the design of bridge pier foundations will be discussed.

### SEISMIC BEHAVIOUR OF MASONRY DOMES AND VAULTS: THE EXAMPLES OF HAGIA SOPHIA IN ISTANBUL AND ST. FRANCIS IN ASSISI – K8

*Croci Giorgio, Ordinario di Tecnica delle Costruzioni, Facoltà di Ingegneria, Università di Roma "La Sapienza", Italy*

Vaults and domes represent the most important elements of historical buildings; their evolution has marked three millennia of architecture. These structures usually present a good intrinsic seismic resistance due to the double curvature, even if, in certain structures sliding in the joints between the blocks may occur.

The main problems are often related with the structures which support the vault or the dome, as is the case of Hagia Sophia , where the problem has been the deformability of the big columns and arches which support the dome to produce high stresses, cracks and finally the collapse of the dome, rebuilt several times during its long history.

In the Basilica of St. Francis of Assisi the problem has been completely different. The double curvature of the cross-vaulted gothic structure is not sufficiently stiff to prevent deformation under the effect of seismic actions. The accumulation of these deformations under the effect of several earthquakes of the past has led, in 1997, to the sudden collapse of two vaults, (and severly damage to the other) although the intensity of the earthquake was less than on the previous occasions.

As far as interventions are concerned, both as preventive measures and as retrofits to strengthen the damaged structures, the engineering challenge is always to find the optimal balance between reinforcements and the respect of the historical value.

The restoration of the Basilica of St. Francis of Assisi has been an important example of the methodology that we have followed to achieve this task, maintaining the traditional concept but also using the most updated techniques and technologies when these are more efficient and reliable.

### MASONRY BUILDING DESIGN IN SEISMIC AREAS: RECENT EXPERIENCES AND PROSPECTS FROM A EUROPEAN STANDPOINT – K9

*Magenes Guido, Dept. Structural Mechanics - University of Pavia, Italy*

The recent development of a new Italian seismic code, conceived as a transition towards the final adoption of Eurocodes, has been an occasion to reconsider thoroughly the current criteria for seismic design of masonry buildings, their experimental and theoretical basis, their consequences on practice. Drawing from this experience, a critical discussion of design criteria is presented, with specific attention to the definition of behaviour factors to be used in elastic analysis and more generally on methods and models for the seismic performance verification of masonry buildings. Necessary and possible developments of design/assessment procedures and code provisions are presented, and research needs are outlined.

### EARTHQUAKE SAFETY OF EXISTING DAMS – K10

*Wieland Martin , Poyry Energy Ltd., Zurich, Switzerland*

In Europe and elsewhere the economically feasible water resources have been greatly developed until the 1970s. Although large dams belong to the first structures, which have been designed systematically against earthquakes since the 1930s, the seismic safety of these dams is unknown, as most of them have been designed using seismic design criteria and methods of analysis that are considered obsolete today. The fact that no major dams have failed during earthquakes and that few lives have been lost (except in the case of tailings dam failures) may give the impression that well-designed dams are safe against earthquakes. We need to re-evaluate the seismic safety of existing dams based on current state-of-the-art practice and rehabilitate existing dams if necessary. Additionally, there are a large number of smaller dams, especially earth structures, which were built for irrigation or water supply by groups with little experience in dam construction. Earthquake effects on these dams have rarely been considered.

## CS1-I: Seismic Input for Design (EC8 and Others)

Monday 13:30 - 15:00 – Room 1

### RE-THINKING SEISMIC HAZARD MAPPING AND DESIGN RETURN PERIODS – ID 1304

*J. Bommer, Imperial College London, UK*

Seismic design codes present earthquake loads in the form of response spectra constructed from mapped values of ground-motion parameters anchored to pre-selected return periods. These return periods – which until recently were almost universally set at 475 years – have generally been selected on a more or less arbitrary basis rather than through quantitative risk management decisions. The recent introduction of different design return periods – mostly longer than 475 years – has generally followed similarly arbitrary selection procedures, with some notable exceptions.

Ground-motion parameters are then mapped at the design return period, and used – in conjunction with the site classification – to construct the response spectrum, which is intended to approximate a uniform hazard spectrum (UHS), having a constant return period across the full range of response periods. The use of site-dependent spectral shapes anchored only to PGA has long been recognised not to result in a UHS, for which reason alternative approaches have been introduced, the most successful and elegant being those employing spectral accelerations at more than one response period. However, as seismic design methods evolve, it becomes necessary to represent earthquake demands in alternative formats, which can necessitate the mapping of many ground-motion parameters, which can become cumbersome (especially when seismic loads are required for multiple performance levels). At the same time, if the designer is concerned with features of the ground motion beyond the elastic response of the structure at its fundamental period of vibration, the UHS concept can be very limiting; there are many good reasons to make earthquake scenarios 'visible' in the presentation of seismic hazard for engineering design.

This paper explores radical alternatives to the presentation of seismic hazard in design codes, proposing the use of quantitative loss modelling as an alternative and rational basis for the identification of loading-performance couples, and the abandonment of the UHS.

### TOWARDS BETTER CHARACTERIZATION OF SEISMIC DEMANDS FOR DESIGN – ID 1477

*E. Miranda, Stanford University, United States*

The goal of seismic design provisions is to provide minimum criteria for minimizing the risk to human life. Another goal, often implicit but sometimes explicitly stated, is to provide uniform levels of risk for structures, depending on their occupancy and use and the risk to society inherent in their failure. In current design codes seismic loading is specified by linear elastic response spectra associated with rare large intensity earthquakes. Even if one remains within the single goal to minimize risk to human life current approaches have a number of problems. Some of them are: (a) although the probability of exceedance at the anchor point(s) of design spectra at rock is explicitly specified, the ultimate goal of the provisions, which is the risk to human life is not; (b) it is not clear that spectral ordinates for all periods of site-modified spectra have a uniform probability of being exceeded; and more importantly (c) it is not clear that current provisions provide uniform levels of risk. Challenges in improved characterization of seismic demands for design are discussed. Particular emphasis is given to challenges in the context of performance based design in which performance expectations exist at increasing levels of ground motion intensity. Challenges will be described in the context of two general possible paths: (a) characterization through improved design spectra; (b) characterization through acceleration time histories. It is argued that parameters that are used to characterize ground motion intensity for the purpose of design, particularly for preliminary design, should be function of structural parameters such as lateral stiffness, lateral strength, energy dissipation capacity that control the response of structures. Examples of seismic demand (intensity) parameters that are function of these structural parameters are provided such as generalized interstory drift spectral ordinates, peak inelastic displacement spectral ordinates, and residual displacement spectral ordinates.

### SELECTING AND SCALING ACCELEROGRAMS FOR DYNAMIC ANALYSIS – ID 1306

*N. Abrahamson, PG&E, United States*

Dynamic, non-linear analysis of structures requires the seismic demand to be presented in the form of acceleration time histories. The most popular approach is to use real accelerograms, scaled to the elastic design spectrum either at the fundamental period of the structure or over a range of periods. Guidance on the selection and scaling of natural accelerograms for use in dynamic analysis is limited, particularly in seismic design codes. In engineering practice there are many widely repeated fallacies regarding this subject, particularly regarding limits on the factors by which accelerograms can be linearly scaled.

This presentation addresses the issues involved in selecting and scaling natural accelerograms for use in dynamic analysis. The key points are the degree to which the selected and scaled records should be compatible with the seismic hazard assessment for the project, and the number of dynamic analyses required to obtain stable estimates of the inelastic response of the structure. An issue that is often overlooked, and which is related to both of these points, is that if the elastic design spectrum is derived using probabilistic seismic hazard analysis, then the ground-motion variability is already accounted for, and should not be included a second time through the variability of spectral amplitudes amongst the selected records. Alternative approaches to selecting records are discussed, and criteria for scaling the accelerograms identified. The advantages of adjusting the accelerograms, through the use of wavelet transformations, to achieve an improved match between the accelerograms and the design elastic spectrum – particularly in reducing the number of dynamic analyses required – are also presented.

## CS1-II: Seismic Input for Design (EC8 and Others)

Monday 15:30 - 17:00 – Room 1

### ESTIMATION OF PERMANENT GROUND DISPLACEMENT FORM NEAR-FAULT STRONG MOTION ACCELEROGRAM – ID 1631

*C. H. Loh, National Taiwan University, Taiwan*
*S. M. Chen, National Taiwan University, Taiwan*
*S. H. Chao, National Taiwan University, Taiwan*

This paper proposes a three-phase algorithm using Discrete Wavelet Transform (DWT) to conduct the baseline correction of near-fault ground motion accelerogram and to estimate the permanent ground deformation. Based on the near-fault ground motion data collected from Taiwan Chi-Chi earthquake, the proposed algorithm is applied. In phase-I analysis the peak ground displacement is estimated from the sifting process of acceleration data through wavelet analysis, and in phase-II analysis the constant level ground displacement trace is estimated from the sifting process of velocity data. Combing phase-I and phase-II the ground deformation trace can be estimated. The estimated permanent ground deformation is compared with the nearby GPS data before and after the earthquake. Finally, the effect of near-fault ground motion on structure is discussed. Through the inelastic response analysis of a SODF system, the system reduction factor, yield spectrum and permanent deformation are discussed.

### FAULT SURFACE RUPTURES: "ASPERITY STRAIN" AND POSSIBLE RELATION TO MAXIMUM GROUND SURFACE SLIPS – ID 1930

*J. Johansson, University of Tokyo, Japan*
*K. Konagai, University of Tokyo, Japan*

There is a need for simple design formulas for estimating "bedrock" fault offset required for a surface rupture to occur. Many researcher have performed model experiments but our ability to predict a surface rupture is still low. By using slip distributions obtained from inversion analyses we test a simple approach of using

the ratio of the maximum slip at an asperity and the distance along the fault dip from the asperity to the ground surface (asperity strain) and comparing it with recorded maximum surface slips. Since surface soils usually behave different in extension (so called active failure) and compression (passive failure) we classify faults into six fault types ranging from reverse (compression) through strike-slip to normal (extension) faults depending on their rake. For strike-slip faults there is a fairly clear trend of increasing ground surface slip with increasing asperity strain. For reverse faults there is no clear trend and for normal faults there to few data available so far. Lower and upper bounds for the asperity strain to cause and not cause a surface rupture are proposed. We compare our results with experimental ones and discuss e.g. how the uplift needed for a surface rupture depends on the fault type.

### EUROCODE 8: COMPLIANT RECORD SETS FOR SEISMIC ANALYSIS OF STRUCTURES – ID 113

*I. Iervolino, Department of Structural Analysis and Design, Italy*
*G. Maddaloni, Department of Structural Analysis and Design, Italy*
*E. Cosenza, Department of Structural Analysis and Design, Italy*

Among all possible options natural recordings are emerging as the more attractive input for non-linear dynamic analysis since accessible waveform databases are available and some evidences show that only a limited number of criteria have to be considered in selection to get unbiased estimation of seismic demand. The Eurocode 8 allows the use of real ground motions for the nonlinear seismic analysis of structures. The main feature to be satisfied is the matching, of the average spectral ordinates of the chosen record set, with the elastic code spectra, not underestimating it more than 10% in a broad range of periods. Code's spectral shape depends on the seismicity of the site, which may be obtained by national seismic surveys (Italian herein), and on the soil conditions. The study presented in the paper investigated the European Strong Motion Database to find accelerograms matching the Euroceode8 prescriptions while accounting for additive constraints believed to matter in the non-linear assessment of buildings. Proposed record sets allow the engineer to choose the one better fitting the purposes of both one-dimensional and spatial analyses. Results refer to soft soils, stiff soils and rock. The accelerogram sets obtained tend to overestimate as minimally as possible the code's spectrum for economical reasons; to have the minimum record-to-record variability; and are not manipulated (i.e. not scaled), to avoid "epsilon" related issues.

### STRONG-MOTION RECORDS SELECTION FOR STRUCTURAL TESTING – ID 5

*J. Douglas, BRGM, France*

When structures are tested against earthquakes, either within laboratories or by computing modelling, observed strong-motion records are commonly used as input. However, the method for selecting records to use is often not stated and it is thought that records are often chosen simply because they are well-known. Until the early 1990s, strong-motion data was relatively difficult to obtain and process and, in addition, the amount of, particularly near-source, strong-motion was limited and therefore using standard records was often the only option. However, since then a number of large well-recorded earthquakes have occurred and also there are many new strong-motion data sources available.

As a snapshot of the state-of-the-art for record selection for structural testing in Europe the proceedings of the last European Conference of Earthquake Engineering (12ECEE) was used. Using those articles concerned with structural testing where strong-motion records are used a summary of the records used and, if stated, why they were selected, is created. Numerous strong-motion parameters of the most popular records are calculated and compared with those estimated by recent ground-motion estimation equations.

Strong-motion records within structural testing could be used simply to validate that the shake table or the computer model functions and to show general aspects of the structures response. For such applications the choice of the strong-motion records is not important and the current method of using well-known records could be maintained. However, more often structural testing is employed in order to understand the characteristics of the modelled structure and to estimate its vulnerability to earthquake shaking. For this a more scientific method of choosing input time-histories is required. The procedure suggested here recognises the observed variety with respect to amplitude, frequency content, duration and shape of earthquake ground motions in order to better understand the characteristics of the structure.

### SEISMIC HAZARD DATA MATCHING THE NEW ITALIAN BUILDING CODE – ID 1949

*C. Meletti, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*G. M. Calvi, Università di Pavia, Italy*
*G. Di Pasquale, DPC - Ufficio Servizio Sismico Nazionale, Italy*
*A. A. Gomez Capera, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*V. Montaldo, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*M. Stucchi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

In 2003 the Italian seismic classification and the seismic code have been deeply changed: the new classification is strictly connected to the technical rules, based on Eurocode 8. This represents an important change and has required a period of time to test and refine the new regulations. A preliminary classification based on previous hazard studies was immediately released, but a medium term upgrade was foreseen based on a new seismic hazard map to be released in 2004. Although the map has been officially adopted only in 2006, a part of the Italian engineering community immediately started asking for varied punctual hazard data, such as different exceedance probabilities, spectral ordinates, etc. This triggered a close interaction between seismologists and engineers that addressed many topics. A significant effort was put to "tune" the different elements that concur in defining the seismic input for design: i) the general criteria supporting the definition of the seismic zones; ii) the ground-motion description in probabilistic terms for each zone; iii) the definition of smoothed elastic and design response spectra; iv) the definition of site amplification effects by means of coefficients related to the characteristics of foundation soil or by specific seismic microzonation studies; v) the definition of advanced design rules to allow the optimal use of hazard information; vi) the definition of seismic rules for the use of innovative technologies in seismic design. As a result, seismologists put together a hazard dataset that allows a clear definition of the design ground-motion and a quantification of the variability of the results. These data are being used to: 1) re-evaluate the reliability of the elastic response spectrum anchor values; 2) introduce seismological constraints on the response spectra for the ultimate limit states and for the damage limitation states; 3) define risk reduction priorities for strategic and relevant structures.

### MULTIPARAMETER SEISMIC HAZARD ASSESSMENT FOR THE THESSALONIKI (N. GREECE) AND VALIDATION OF THE RESULTS – ID 1913

*C. Papaioannou, ITSAK, Greece*

The broader Thessaloniki metropolitan area (N. Greece) is characterized by strong shallow normal faulting earthquakes. Detailed geological and geophysical investigations were carried and their synthesis with seismological data resulted in the determination of the parameters of the active faults and the background seismicity in the broader area. The parameters of these faults were used for a seismic hazard study using as parameters the macroseismic intensity and peak horizontal acceleration and a hybrid input model consisting of line (faults) and areal sources Using the available macroseismic data site specific attenuation relations were proposed for the macroseismic intensity. For the peak ground acceleration two different predictive relations were applied following the results of a recent study concerning the different characteristics between the predicting relations of small-to-moderate ($M< 5.0$) and moderate-to-large earthquakes ($M\geq 5.0$). Seismic hazard calculations were performed using the FRISK88M computer code properly modified for considering for every site the two different attenuation relations. The results are presented in graphs and maps.

The distribution of the observed intensity data were used for the validation of the probabilistic hazard results and the compilation of the maximum acceleration and intensity maps for the area. The de-aggregation of the hazard analysis results for macroseismic intensity and acceleration for mean magnitude and distance and for various mean return periods are also presented and discussed.

## CS1-III: Seismic Input for Design (EC8 and Others)

Tuesday 10:45 - 12:15 – Room 1

### A METHODOLOGY FOR THE IDENTIFICATION OF DESIGN EARTHQUAKE INPUTS – ID 963

*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*
*D. Malavolta, DISTART - Department of Civil Engineering, Italy*

In recent years, Performance Based Seismic Design (PBSD) has played a central role for research works in the field of seismic engineering. The core idea of the PBSD is the probabilistic assessment of the structural performances due to seismic action [Bertero and Bertero 2002, Moehle and Deierlein 2004, Zhang et al. 2004]. From a practical point of view, following the PEER framework [Cornell and Krawinkler 2000], this assessment can be achieved through an articulated procedure which can be summarized in the following subtasks [Zhang et al. 2004]: · Probabilistic Seismic Hazard Analysis (PSHA) or simply Hazard Analysis (HA); · Probabilistic Seismic Demand Hazard Analysis (PSDHA); · Probabilistic Seismic Capacity Analysis (PSCA) also called Fragility Analysis; · Seismic Reliability Analysis (SRA). This paper focuses mainly on the correct identification of the dynamic inputs ("bins" as defined by Giovenale et al. [2004] or "EPI groups" as defined hereafter by the authors) to be used in the PSDHA subtask. In detail, the paper introduces a general framework ("methodology for EPI group creation") for the rationally-organised treatment of the latest contributions in terms of ground motion parameters which have a substantial effect upon the structural response. Among the factors taken into account in the proposed methodology for the correct identification of the EPI group, we mention the use of vector-valued IMs [Baker and Cornell 2004, Trombetti et al 2003], the recently proposed parameter "epsilon" (as obtained by disaggregation analysis [Baker and Cornell 2005]), magnitude "MS", site to epicentre distance "R" and relative number of near field records.

### SETTING UP REAL OR ARTIFICIAL EARTHQUAKE RECORDS FOR DYNAMIC ANALYSIS – ID 899

*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*
*M. Marques, Faculdade de Engenharia da Universidade do Porto, Portugal*
*R. Monteiro, Faculdade de Engenharia da Universidade do Porto, Portugal*
*P. Delgado, Instituto Politécnico de Viana do Castelo, Portugal*
*X. Romão, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*

Within the scope of non-linear seismic structural analysis, the adequate selection of the ground motion records that will be considered is of fundamental importance in order to assess the adequacy of the seismic input and, simultaneously, to minimize the associated variability. This selection can be performed by analysis of the ground motion records or by analysis of their effects on the structures. The proposed paper will present a study on the use of different ground motion scaling techniques in order to identify particular records from an available strong-motion database that contribute significantly to the scatter. Results from the analysis of a bridge and a framed building will also be considered. For this purpose, a cluster analysis based procedure is proposed to group accelerograms with similar behaviour, thus eliminating the remaining ones. The proposed paper will also present a study attempting to reduce the number of necessary records that are requested to assure the same average response that one would get if using a complete group of ground motions scaled by an efficient scaling technique. One of the main issues on the subject of ground motion selection is related to the use of real earthquake records versus artificial ones. The proposed study will establish a comparison between real and artificial accelerograms in terms of variability, in which the latter are generated in order to be spectrum-compatible with the first ones. The main conclusions aim to define practical rules for ground motion scaling, the minimum number of accelerograms that are requested to obtain a stable average structural response, and to aid in the decision of whether the use of real or artificial ground motion records is more appropriate.

### DESIGN FORCE RATIO SPECTRUM FOR PERFORMANCE-BASED DESIGN IN CASE OF MULTIPLE EVENTS – ID 46

*S. Das, Indian Institute of Technology, India*
*V. K. Gupta, Indian Institute of Technology, India*
*P. K. Ramancharla, Indian Institute of Technology, India*

The earthquake-resistant design methodology in most codes of practice is based on ensuring 'no collapse' during the most severe event expected at the given site and on providing a minimum ductility in the structure so that much of the input energy is dissipated through plastic deformations. Evolution of the performance-based design over the last decade has seen a few performance levels added up to this so that the structure remains functional even after a moderately strong event. This methodology however overlooks the possibility that in case of multiple earthquake events expected during the design life of the structure, the structure may get gradually damaged and that it may not be feasible to carry out repairs in the structure after every event. As a result, the structure may collapse earlier than expected and perhaps during an event of moderate intensity. To address such concern, a new spectrum, called as design force ratio (DFR) spectrum, is proposed. DFR spectrum gives the ratio by which the design yield force level of a single-degree-of-freedom structure should be increased such that the damage caused by a number of earthquake events expected to occur during its lifetime is limited to a specified level. This spectrum is based on the application of the order statistics approach for the estimation of expected magnitudes of earthquake events likely to occur during the lifetime of the structure. A numerical study is carried out for a hypothetical seismic region and DFR spectra are obtained. It is assumed that the return periods of earthquakes follow exponential distribution over the entire range of magnitudes. It is assumed that the earthquake ground motion for an event may be characterized via power spectral density function, and the structural response is estimated by considering equivalent linear oscillator with event-to-event degrading strength and stiffness characteristics.

### CONSTANT DUCTILITY RESPONSE SPECTRUM BASED ON CONSTANT YIELD DISPLACEMENT CONCEPT – ID 10

*M. Safar, McMaster University, Canada*
*A. Ghobarah, McMaster University, Canada*

Inelastic response spectra are used extensively in earthquake engineering practice. Their importance is increasing with the current increasing interest in performance-based earthquake engineering. A new methodology for constructing constant ductility response spectra (CDRS) based on constant yield displacement load-deformation model is proposed. The proposed methodology presents rational basis for adopting the concept of constant yield displacement to modify the recently presented yield point spectrum. While the yield point spectrum is an alternative representation of the conventional CDRS, the proposed methodology presents a dynamic basis for constant yield displacement concept. Details

of the proposed methodology are discussed and illustrated. The proposed spectrum provides the needed rational adjustment to the CDRS, since unique combinations of strength and stiffness are associated with a certain yield displacement value and increasing ductility levels.

### COMPUTING A 'REASONABLE' SPATIALLY VARIABLE EARTHQUAKE INPUT FOR EXTENDED BRIDGE STRUCTURES – ID 1601

*A. Sextos, Aristotle University Thessaloniki, Greece*
*A. Kappos, Aristotle University Thessaloniki, Greece*
*V. Kollias, Denco S.A., Greece*

During strong ground motion, it is expected that bridge structures are subjected to excitation that is non-uniform along their longitudinal axis in terms of amplitude, frequency content and arrival time, a fact primarily attributed to the wave arrival delay, their loss of coherency and the effect of local site conditions. Although considerable research has been carried out over the last twenty years in all the aforementioned directions, the knowledge gained has only partially been reflected on modern seismic code provisions. Currently, it is only Eurocode 8 - Part 2 that has adopted provisions for tackling this complex phenomenon of asynchronous motion, which have been revised in its final version. As a result, the goal of this paper is to assess these current provisions by focusing on some typical bridge structures. Using a special purpose computer program, the simplified approach proposed by EC8 is critically compared with the results of more refined analysis; the latter involves multiple support excitation of the bridges using pier-dependent artificial accelerograms that account for all the aforementioned three main sources of spatial variability of ground motion. The results indicate that the new EC8 provisions are easy to apply and provide a good qualitative prediction of the asynchronous motion induced distress of the bridge. However, in certain cases, their application is subject to limitations and has to be performed by exercising engineering judgement.

### A CRITICAL REVIEW OF THE CHANGING SEISMIC DESIGN CRITERIA FOR LNG PLANTS – ID 1162

*Z. Lubkowski, Arup, UK*
*X. Duan, Arup, UK*
*J. Pappin, Arup, China*
*M. Willford, Arup, UK*

The seismic design criteria for LNG tanks are described in EN 1473 for projects in Europe and NFPA 59-A for projects in the United States. These documents define the return periods and performance requirements for the different elements of an LNG plant, for example LNG tanks are required to remain operational in a rare or operating basis earthquake (OBE) and to maintain safety-related operational functions after a very rare or safe shutdown earthquake (SSE).

Revisions to NFPA 59-A over the last decade has see the SSE return period reduce from 10,000 years in 1996, to 4,975 years in 2001 and 2475 years in the 2006 edition which is to be published later this year. The current edition of EN 1473 defines the SSE return period as 10,000 years, however, the proposed revision is quoting a reduction to 4,975 years, and there is a will from the energy community to ensure uniformity between the two codes, hence a further reduction is likely before the revision to EN 1473 is published. These reductions in return period have clearly reduced the level of safety for the critical components of an LNG plant. Is this reduction is safety justified?

This paper will examine the appropriateness of the proposed changes to these seismic design requirements by comparison with other critical facilities, such as nuclear power stations, dams and offshore oil platforms. The authors will also address the impact of these proposed changes in areas of high, moderate and low seismicity. Finally a rational framework of return periods and performance criteria will be proposed.

## CS2-I: Historical Investigations of Earthquake Effects, Damage and Vulnerability

Tuesday 13:30 - 15:00 – Room 15

### LESSONS LEARNED FROM PAST EARTHQUAKE IN IRAN – ID 397

*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*

In this paper, after a brief description of past earthquakes from structural point of view, evaluation of the common modes of failures of various types of buildings, implementation of engineering practice and know-how, lessons learned from past earthquake in Iran and future challenges to scientist, engineers and people have been presented. It is seen that despite the technological advances and improvements of the codes, the modes of the failure in most of the adobe, masonry, non-engineered and engineered buildings are still the same. The damages and losses in the earthquakes are not due to lack of know-how or lack of use of the advance technology in asiesmic design and construction, but it is mainly due to: inadequate planning and development with respect to seismic hazard; inappropriate design and construction; poor code and law enforcement and lack of technical supervision; and finally poor implementation of existing knowledge. In other words, we have not learned all that we could have from past earthquakes; and the scientific communities has not been successful in offering useful, practical, affordable and simple methods solutions for the user to use it. Thus, by classification of the problems; we need to put the scientific knowledge into Usable, Simple, Affordable and Doable form as well as translating the safety into economic, social and human Value for people to accept and understand.

### HISTORICAL DAMAGE DATA AND MICROZONATION. AN APPLICATION TO SENIGALLIA 1930 EARTHQUAKE – ID 1267

*E. Speranza, Italy*
*A. Goretti, SSN-DPC, Italy*
*M. Dolce, DiSGG, Italy*

Recently several successful methods using vulnerability and damage data set collected after an event (1997 Umbria-Marche, 1998 Pollino and 2002 Molise earthquakes) have been proposed in the framework of microzonation analysis. The present paper shows an attempt for evaluating site effects from historical damage data. The 1930 strong earthquake of Senigallia, a small town of Central Italy on the Adriatic coast, was selected as a case study. This seismic event produced heavy damage to buildings and several collapses, mostly affecting top storeys, resulting in IMCS=VIII-IX. Following the earthquake, massive reconstruction works were carried out and, in several cases, many dwellings as well as entire building stocks were completely demolished and then rebuilt. The building types and the suffered damage at the time of the earthquake have been carefully evaluated by a documentary and photographic recognition of the seismic damage and of the reconstruction works. The damage occurred to buildings was investigated through the examination of pictures taken after the earthquake or during the emergency works. Building type and damage classification, together with the related pictures, were then geo-referenced to a cadastral map. Local seismic intensity has then been obtained from damage and building type data, by filtering damage by the building type vulnerability, in order to have an effective measure of the ground shaking. To get an estimate of the ground motion, the FOSM-BLUE updating methodology was utilised, incorporating uncertainties in the observed building type and damage, as well as in the expected seismic vulnerability of buildings. The spatial correlation of the ground motion was also introduced in the analysis. Finally, spatial cluster analysis based on the ground motion amplification was performed, providing the areas that can be considered homogeneous in terms of amplification. The results are discussed and compared with geological maps.

### CORRELATION OF SEISMIC ACTIVITY WITH THE ARCHITECTURAL-HISTORICAL INHERITANCE IN THE NORTHERN GEORGIA – ID 1303

*D. Moshe, The College of Judea and Samaria, Israel*
*V. Zaalishvili, Geophysical Center of Experimental Diagnostics, Russian Federation*

It was accepted for a long time that on the Caucasus that is characterized by the moderate seismicity, maximum design intensity is not very high in large part of the territory. It allowed to create a conception of relatively inexpensive buildings design and was a foundation of certainly progressive plans realization of speeded building up for the masses. Spitak earthquake (Armenia, 1988) had shown that greater earthquakes can occur there. Unfortunately mentioned data were not included in the corresponding seismic zonation maps of the former USSR (1978). More than that design intensity of Spitak for example was even reduced. On the other hand preservation of the architectural–historical constructions located in the Central part of the North Georgia in any case with the history of thousand years is a foundation for limitation of possible occurrences of high intensity. Racha earthquake with M=7.1(Georgia, 1991) had shown that most of the religious buildings were destroyed and some seriously damaged. The analysis of the data of engineering macroseismic inspection of Racha earthquake shows, that most cult constructions have been destroyed, and separate have been seriously damaged. The features of earthquake in the area of investigated region is shown in current work. In the work there is considered design of synagogue in city Oni, that was constructed not so long ago (1895). Thus features of damages in a massive construction where initially there was no amortization of constructive elements before earthquake are shown. Further there are shown results of comparison of earthquake effect on other cult constructions (church Barakoni, Mravaldzali, etc.), and living building stock. The interrelation between local conditions and consequences of earthquake is established. The concept of preservation of the existing cult constructions representing an architectural - historical value, in conditions of high seismic hazard is developed.

### URBAN SEISMIC SCENARIO OF THE OLD NUCLEI OF ALGIERS (ALGERIA) DURING THE XVIIITH CENTURY – ID 1580

*A. Foufa, U. BLIDA, Algeria*
*D. Benouar, USTHB, Algeria*

This research work presents an urban seismic scenario of one of the greatest historical earth-quakes which have stricken the city of Algiers. To establish the urban seismic scenario at the an-cient time means the localization of the effects of the earthquake at the time they shook the city. It assumes a research of the urban aspect of Algiers over the time when the most significant earthquake happened. This must appear with the localization of the centre or the core of the city, its habitat, its streets and its major buildings. It can be achieved by the examination of the vari-ous sources available recalling the urban aspect of the city to each period considered, when it is possible, and to superimpose them on the assessment of the damage which occurred at that time. The findings will be mapped locating as much as possible the damage induced by the earthquakes in the Medina of Algiers. The aim of this work is not to rewrite the history of Algiers but to lo-cate the areas damaged in the past in order to establish the future scenarios for a better protection of our built cultural heritage. Algiers was stricken by three great earthquakes in the past. The first one at the medieval time in 1359, the second one at the end of the 16th century in1673, and the last big one at the beginning of the 18th century in 1716.The data collected are unfortunately very rare, and it was difficult to give a complete aspect of each earthquake. We will try to recall the urban seismic scenario only for the 1716 earthquake of which we collected sufficient informa-tion. Some information, which we could collect, is found confined in heterogeneous sources.

## CS2-II: Historical Investigations of Earthquake Effects, Damage and Vulnerability

Tuesday 15:30 - 17:00 – Room 15

### DAMAGE FIELDS AND SITE-EFFECTS: INVESTIGATIONS ON EARTHQUAKES OF THE 19TH AND 20TH CENTURY IN SWITZERLAND – ID 1619

*S. Fritsche, Swiss Seismological Service, Switzerland*
*D. Fäh, Swiss Seismological Service, Switzerland*

Among the strongest earthquakes that struck Switzerland in the 19th and 20th century are the events of Visp (1855, Mw = 6.4) and Sierre (1946, Mw = 6.1) both in the region of the Valais, as well as the event of Sarnen (1964, Mw = 5.7) in the central part of Switzerland. All of them caused moderate to heavy damage to several hundred buildings.

We investigated these events in order to understand to what extend site-effects were responsible for the characteristics of the damage fields. In doing so, we used a multidisciplinary approach combining historical and geophysical investigations. The historical research focused on the reconstruction of the damage field, including secondary geological phenomena such as rock fall or liquefaction. Particularly the damage of the events of 1855 and 1964 in Central Switzerland are very well documented and allowed a very accurate reconstruction of the damage fields. Less complete, but nevertheless applicable for further research, are the historical outcomes concerning the 1946-event of Sion/Sierre. In a second step we analyzed the geological site conditions of the damaged buildings. Beside measurements of the fundamental frequency of resonance on a large number of sites, geological and borehole information were collected and compared to the observed damage. For all events our results show a clear correlation between the damage field and the local site condition. In this contribution we present the settings and outcomes of these investigations and discuss the problems and chances of such an approach.

### LUIGI POLETTI AND THE 1833 PROPOSED RETROFITTING OF THE PALAZZO COMUNALE IN FOLIGNO (ITALY) – ID 1393

*L. Sorrentino, Structural and Geotechnical Engineering Department, Italy*
*M. Antonini, I Architecture Faculty "La Sapienza", Italy*
*D. Bruccoleri, I Architecture Faculty "La Sapienza", Italy*

On January 13, 1832 a X degree Mercalli-Cancani-Sieberg (MCS) intensity earthquake, with epicentral area in the Topino river valley, hit Central Italy and was felt with a VIII° MCS intensity in Foligno. After that event the architect Luigi Poletti (1792-1869) designed a new façade for the Palazzo Comunale, in order to retrofit it. Poletti was a practitioner who during his life confronted himself more than once with situation related to catastrophic events and serious structural distress. In 1829-1845 he designed the soil buttressing of the Tempio della Consolazione in Todi, damaged by the 1815 earthquake; in 1833-1869 he was in charge for the reconstruction of Saint Paul basilica in Rome, almost destroyed by the 1823 fire; in 1832-1842 he was appointed head engineer for the restoration of the Santa Maria degli Angeli basilica in Assisi, damaged by the 1832 event; in 1834-1869 he reconstructed the church of San Venanzio in Camerino, hit by another earthquake in 1799. All his experience with constructions in seismic prone areas was distilled in the Norcia building code, which he contributed to write after the 1859 event. In this paper the seismic catalogue of Foligno is reconstruct, in order to compare building and seismic histories. Archive accounts for previous damages are presented. Poletti's proposal was basically that to build a buttress in front of the pre-existent façade, giving it an architectonically feasible shape. This solution, later on discharged for the basically similar but less expensive one by architect Antonio Mollari, is illustrated through contemporary as well as new descriptions and drawings, is compared both to others presented at that time and with significant historical precedents. Its mechanical effectiveness is checked by

means of simple limit analysis.

### THE 1356 BASEL EARTHQUAKE FROM A HISTORICAL STANDPOINT: OLD WINE IN NEW WINESKINS? – ID 24

*M. Gisler, Swiss Seismological Service ETHZ, Switzerland*
*G. Schwarz-Zanetti, Swiss Seismological Service ETHZ, Switzerland*
*D. Fäh, Swiss Seismological Service ETHZ, Switzerland*
*V. Masciadri, Philologisches Seminar University of Zurich, Switzerland*
*D. Rippmann, Historisches Seminar University of Zurich, Switzerland*

The 1356 Basel earthquake is acknowledged to be one of the largest known seismic events in the northern Alpine region. Endeavours to study its damage area or its possible source delivered several new insights into this event. Modern studies that concentrate on the historical output of the event in contrast are rather occasional; even more as most documents in use are well known since mid-19th century. A current project at the Swiss Seismological Service seeks to look into the event with an interdisciplinary approach, integrating historical, seismological, archaeological, paleoseismic, and engineering techniques. In what follows the significance and information value of historical records will be discussed. The effort is based on three levels:

1) Research of contemporary documents within the supposed quake area, with an emphasis on the region outside of the city of Basel, as the examination of the later is mainly ventured by the archaeological team. We are trying to concentrate on records that can be dated very close to the event, as only a small number of such documents is known so far. This may include documents noting the reconstruction of damaged buildings rather than providing information of the earthquake itself. 2) A very complex situation is given by the fact that the destruction of 60 or more castles in the Basel region is reported. Whereas this number is cited even in documents produced close to the event, a list of the names of the castles on the other hand is dated some 60 and more years after the event. In our presentation we will consider some historical grounds for this list. 3) We will furthermore very shortly look at some problems concerning the use of chronicles that hold information on the earthquake, and discuss the evaluation of content and value of the provided information therein.

### HISTORICAL ASPECTS OF EARTHQUAKE ENGINEERING FROM AN INTERNATIONAL PERSPECTIVE – ID 1350

*R. Reitherman, Consortium of Universities for Research in EQ Eng, United States*

Based on the author's Earthquake Engineering Research Institute (EERI) - Federal Emergency Management Agency (FEMA) Professional Fellowship research, this paper notes similarities and differences concerning the ways earthquake engineering has developed in different countries.

Approximately ten countries have been studied and sources of information and experts in those countries consulted, with a disciplinary focus on the structural and geotechnical engineering branches of civil engineering. The development of the quantitative aspects of the applied science of earthquake engineering is emphasized, rather than prescriptive or traditional construction techniques. The scope extends to some extent into the field of seismology, with regard to this question: What early developments in seismology were essential for engineering techniques to progress, and vice versa?

Some recurring factors are encountered in the evolution of earthquake engineering in many nations, although the exceptions are as interesting as the cases that follow a common pattern:

- An earthquake occurs that is sufficiently damaging and which also occurs when a country's engineers are ready to employ their art and science to contend with earthquakes.
- The establishment of a nation's first seismic provisions in a building code as the key development in engineering practise as well as an important stimulus for engineering research and education.
- The significance of the start of a country's first university engineering programme, however small initially, from which follows increasing numbers of educators and researchers and the diffusion of knowledge into engineering practise.
- Significant cross-pollination or "importation" of learning from other countries as earthquake engineering becomes more internationalized.
- Engineering as primarily a problem-solving profession; seismology as primarily a knowledge-seeking science, especially the branch concerned with Earth's interior rather than seismic ground motion at the surface. An influential though initially small number of strong motion seismologists and engineers have bridged this gap between the two disciplines.

## CS3: Applications of the EMS-98 and Related Future Evolutions

Wednesday 13:30 - 15:00 – Room 15

### PROPOSALS FOR EMS-98 QUESTIONNAIRES – ID 702

*P. Alves, Inst. de Meteorologia, IP, Portugal*

Macroseismic questionnaires are a natural result of the intensities scales in the sense they are the natural basis for their application. In 1998 the European Macroseismic Scale was published but despite extensive guidelines and background material, a way of applying it in an integrated form was not supplied. Given the complexity and detail of the EMS-98, the design of a questionnaire is not a simple task. However, in order to compile, analyse, evaluate and archive macroseismic information some attempts to develop such tool must have to be done, and this is one of them. Three questionnaires for the assignment of macroseismic intensity are proposed: the first one concerning the complete scale; the second one between 7 and 12 which is a more specific proposal form for FITESC (ESC Field Investigation Team) and a third one for the range between 1 and 6, applicable for the case of a low level felt earthquake, almost without damages. A form for an intermediate range (4-9, for example) uses almost the same structure and space of the form with the complete range of intensities and for that it is not useful. The questionnaires were designed: to be as faithful as possible to the concept of the scale and to the intentions of the authors; to show all the support information for a precise application of the scale; to keep in the form all the "raw" information to assign the intensity including, for example, information provided by individual observers (keeping this information, future re-evaluation, if necessary, is always possible); to be a tool, as friendly as possible, for in situ work in rough conditions; to provide an easy way to archive huge amounts of information; to be a useful tool for (re)evaluation of documentary data. Some fulfilling and future developments examples are discussed.

### APPLICATION OF EMS-98 IN FRANCE: USE OF THUMBNAIL IMAGES FOR INTENSITY ASSESSMENTS THROUGH THE BCSF WEB SITE AND EXTENSION OF THE MACROSEISMIC SURVEY TO THE FRENCH WEST INDIES – ID 1727

*M. Cara, EOST, France*
*C. Sira, EOST, France*
*A. Bernard, EOST, France*
*A. Schlupp, EOST, France*

Several attempts have been made at the Bureau Central Sismologique Français (BCSF-EOST) to run automatic procedure for evaluating macroseismic intensities. Basic macroseismic information used in these simulations comes from collective and individual forms which have been designed to fulfil the requirement of the EMS-98. These forms which are filled either on paper format or directly on the BCSF web site are automatically converted into an ASCII file containing the coded answers to the questionnaires. The attempts we have made to design an automatic procedure based

on a logical tree mimicking the human expertise failed at producing high scores when evaluating the macroseismic intensities. For this reason, the individual Internet questionnaires have been completed with clickable thumbnail images illustrating some representative situations encountered at the different degree of intensity. Much higher scores may be obtained when using the thumbnails images as a primary source of information when running our automatic procedure. Exotic answers from individuals are then easily detected when the clicked image is contradictory to the other part of the questionnaire. It is likely, however, that passing from individual questionnaires to an evaluation of the EMS-98 intensity of the given area will be a tricky problem above intensity I=VI. Statistical estimation of the number of damaged buildings would then be very difficult, if not impossible, to assess from the sporadic testimonies sent by individuals. Furthermore, our experience convinced us that it is very difficult for an individual to say in which type of construction he is living. Field visit by an expert is the only way to get some confidence above intensity VI. We illustrate different example of intensity evaluations we have performed since 2003 in France and in the French West Indies using either collective forms or individual Internet questionnaires.

### EXPERT JUDGEMENT VERSUS AUTOMATIC AND STATISTICAL ANALYSIS OF MACROSEISMIC QUESTIONNAIRES – ID 21

*P. Kästli, Swiss Seismological Service, Switzerland*
*M. Gisler, Swiss Seismological Service, Switzerland*
*D. Fäh, Swiss Seismological Service, Switzerland*

Automatic processing of internet-based macroseismic questionnaires allows for a fast overview of the effects of a seismic event. Such a procedure has been implemented at the Swiss Seismological Service (SED). The tool can produce a shake-map within tens of minutes after an event. Macroseismic observations are available from many places and local soil characteristics are already included. Automatic processing of macroseismic data needs algorithms that simulate the work of an analyst. While intensity assessment was traditionally an expert judgement, the European Macroseismic Scale (EMS) provided a statistical framework for the analysis of earthquake observation data. However, as data quantities and acquisition procedures often do not fully cope with the needs for a statistical analysis, expert judgement and "mixed mode" analysis is still common throughout Europe. This paper compares the results of three techniques to assess macroseismic intensities: - Assignment by a human expert holding a general overview of quantitative and qualitative base data; - Pure statistical application of EMS scale to derive intensity from structured earthquake questionnaires. - The "virtual expert" routine of the SED macroseismic shakemap software which partly relies on statistical procedures, partly imitates human expert judgements. Furthermore, we analyse three different data acquisition techniques (spontaneous reports – email questionnaires to interested people – paper questionnaires to anybody) and compare their impact on derived intensities. The investigation bases on intensity assignments of EMS I to VI of the Swiss Seismological Service for small to medium earthquakes in time period between 2003 and 2005.

### CONVERSIONS BETWEEN OLDER INTENSITY SCALES AND EMS-98 – ID 542

*R. M. Musson, BGS, UK*
*G. Grünthal, GFZ, Germany*
*M. Stucchi, INGV, Italy*

Ideally, direct conversion between intensity scales should never be made. The correct procedure is always to reassign intensity values to the original data using the desired scale. However, there are many cases where this is not practical, and some guidance is needed to convert data from older scales to newer ones. The problem is that any set of intensity values is a compound of the scale used and the working practices used, and the latter are usually undefined and obscure. Thus, intensity values are likely to vary more between two seismologists using the same scale than between two scales used by the same seismologist (at least for twelve-degree scales). It follows that comparison of sets of assigned values using different scales will give insight into those data sets, but will probably not reveal general relationships between the two scales. To get a general picture of the equivalence between two scales, the best procedure is to treat the definition of an intensity degree in scale A as if it were data, and assign a value to it using scale B. Following this procedure, the relationship between major twelve-degree scales (such as MSK, MMI and MCS) and EMS-98 is more or less 1:1. The chief difference between these scales is not so much the level of shaking represented by each degree, but the extent to which the wording of the scale guides the user to make the correct intensity assignment. Thus intensity values that have been assigned using (say) MMI and then converted to EMS-98 will not be as reliable as those assigned directly using EMS-98.

### COMPARISON AND REFINEMENT OF TWO EMS-98 DERIVED VULNERABILITY METHODS: TOWARDS A UNIQUE DEFINITION. – ID 909

*A. Bernardini, University of Padova, Italy*
*S. Giovinazzi, University of Genoa, Italy*
*S. Lagomarsino, University of Genoa, Italy*

For the seismic vulnerability assessment of ordinary buildings, the definition of a unique observational vulnerability approach in terms of vulnerability classes, building typologies, hazard and damage description should be aimed for the European countries in order to implement coherent and comparable vulnerability analyses. The vulnerability model implicitly contained in the European Macroseismic Scale EMS-98 (Grunthal 1998) hold these requirements so that proposal for EMS-98-derived vulnerability approaches have been done. Based on the theory of the random sets, Bernardini (Bernardini, 2005) have used the qualitative measures of the scale to derive upper and lower bounds of relative frequencies of the damage grades for every EMS-98 class and macroseimic intensity. Lower and upper Damage Probability Matrixes (DPM) and interpolating vulnerability curves, have been, as well, obtained by Giovinazzi and Lagomarsino (2004) from the definitions provided by the scale, by the joint use of Fuzzy Set Theory and of the Probability Theory for EMS-98 vulnerability classes and building typologies. Aiming to a common and complete definition for an European Macroseimic vulnerability method this paper is addressed, on one hand, to compare the aforementioned proposals and, on the other hand, to refine them and to introduce innovative aspects with regards to the definition of the vulnerability model for the building typologies. The comparison is addressed to highlight the differences and the common aspects of the hypothesis at the base of the two proposed approaches and to compare the results in terms of the damage distributions, the vulnerability and the fragility curves derived for the EMS-98 vulnerability classes. Original proposals are put forward to derive frequencies of the expected damage for the building typologies and to employ Bayes theorem to updated these expected frequencies, when the availability of further data on the building stock allows identifying sub-typologies.

### E.M.S. - A METHOD TO REDUCE THE UNCERTAINTY OF THE STRUCTURE VULNERABILITY CLASSIFICATION – ID 1124

*G. Zuccaro, Centro Studi PLINIVS - Universtity of Naples, Italy*
*F. Cacace, Centro Studi PLINIVS - University of Naples, Italy*

In the paper a method to assign building structure typologies structures to vulnerability classes provides by European Macro-seismic Scale reducing the uncertainty of classification showed in the EMS is presented. The EMS '98 so as the more recent versions of the scale defines the standard criteria to classify the buildings in six vulnerability classes. The assignment is mainly based on the vertical structure type, and is affected by a wide range of uncertainty. In this way, for example, a "massive stone" building is classified as "C", but it can also be classified as "B" or "D". The research proposes a procedure to calibrate the E.M.S. vulnerability classification reducing the uncertainty range of the assignment. The procedure has been developed within the activities of the

Research Project SAVE (Strumenti di Analisi di Vulnerabilità degli Edifici esistenti) supported by National Depart. of Civil Protection trough GNDT-INGV, represents a quick technique that, based on "first level" data, evaluates the seismic structural vulnerability by assigning single structures to a building type family of which the behaviour under seismic action is expected. The procedure, although is based on "poor information", introduces several parameters that allow to take into account, in the final vulnerability estimation, all the information possibly available on the structure characteristics about the building (vertical and horizontal structure types, layout, wall dimensions, geometry, ties, materials etc.). The procedure has been calibrated using a large data-base containing all the damage data surveyed in several seismic events of the past in Italy considering more then 165.000 buildings. Finally an application of the procedure to the "public and strategic buildings" in Campania Region is reported; the results of the punctual sample check "in situ" are reported and a very good reliability of the procedure in this case has been found.

## CS4-I: Strong Motion : Use and Modelling

Monday 15:30 - 17:00 – Room 2

### STOCHASTIC FINITE-FAULT MODELING OF STRONG-MOTION RECORDS FROM THE 2003 BAM EARTHQUAKE IN IRAN – ID 13

*A. Nicknam, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*S. Yaghmaei, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*A. Yazdani, Iran University of Science and Technology, Iran (Islamic Republic Of)*

A simple and powerful method in the simulation of strong ground motion, vastly used in recent researches is the stochastic finite-fault method proposed by Atkinson and Beresnev. This method is used for simulating the recorded destructive 26 December 2003 Bam earthquake in southern part of Iran. In this approach the finite-fault plane is subdivided into elements and a stochastic spectrum is assigned to each element. The ground-motion amplitudes are simulated as a summation of stochastic point sources. The results of the synthesizing ground motion such as acceleration time history, response spectra are compared with those of observed data. Good agreement of time series parameters (i.e. PGA, Sa, Sv and Sd) are obtained which confirm that selected source parameters were satisfactory reliable.

### ON THE APPLICABILITY OF ONE-DIMENSIONAL CRUSTAL STRUCTURES FOR GROUND-MOTION SIMULATION – ID 18

*J. Douglas, BRGM, France*
*H. Aochi, BRGM, France*
*P. Suhadolc, University of Trieste, Italy*
*G. Costa, University of Trieste, Italy*

Ground motion simulation methods, such as the finite-difference method (FDM) or the modal summation technique, require a model of the structure through which the seismic waves pass in terms of density, velocity and attenuation parameters, such as Q. The use of such structural models within simulations means that travel path effects, such as the constructive interference of different phases, can be modelled. Currently one-, two- or three-dimensional models are used without much description of the benefits of using a particular dimension of model. Within FDMs, a 2D or 3D structure can be assumed without a significant increase in computational time. One-dimensional models have the advantage of yielding results that are easier to interpret in terms of phases and also they require only one set of simulations for all considered horizontal source and site locations. In addition, the method introduced by Douglas et al. (2004) for the incorporation of the effect of crustal structure into empirical ground motion estimation equations is only practical for one-dimensional structures.

The purpose of this article is to investigate when two-dimensional structures provide significantly different results than using an average one-dimensional model. This quantitative analysis is based on an analysis of a series of FDM simulations using a variety of one- and two-dimensional structures. The difference between the 2D and the derived 1D structure is quantified by a single parameter that seeks to characterise how two-dimensional the structure is. The maximum size this parameter can be before a 2D structure is required for accurate modelling of ground motions is assessed based on the series of FDM simulations. The purpose of this proposed technique is to provide guidance as to when 2D structures should be used or where 1D structures are sufficient, without the requirement of performing many simulations.

### MODELING OF DISTRIBUTION OF GROUND MOTION PARAMETERS DURING STRONG VRANCEA (ROMANIA) EARTHQUAKES – ID 363

*V. Sokolov, Geophysical Institute of Karlsruhe University, Germany*
*K. P. Bonjer, Geophysical Institute of Karlsruhe University, Germany*

The intermediate-depth (70-140 km) earthquakes of the Vrancea (Romania) source zone produce the most significant seismic hazard to Romania and its neighboring countries. Analysis of macroseismic and instrumental data from the Vrancea earthquakes revealed several peculiar effects, which can be summarized as follows: (1) the earthquakes affect very large areas with predominantly NE-SW trending extensions; (2) the local and regional geological conditions control the variation of amplitudes of the ground motion to a larger degree than magnitude or distance. Four major Vrancea earthquakes occurred during the last century: November 10, 1940 (MW = 7.7), March 4, 1977 (MW = 7.4), August 30, 1986 (MW = 7.2) and May 30, 1990 (MW = 6.9). An extensive set of macroseismic data for these events is available from the Romanian, the Bulgarian, the Moldavian and Ukrainian territory and near distant on-scale recordings of ground acceleration exist for the 1986 and the 1990 earthquakes from different localities. This data set gives a unique opportunity to control quantitatively the modeling of the ground motion parameters of such large events. The modeling was performed on the basis of source scaling models (Fourier amplitude spectra, FAS) for the Vrancea earthquakes, as well as site response characteristics, which were recently analyzed by the authors. When using FAS as input parameter in seismic hazard analysis, it is possible to obtain site-dependent estimations of various strong ground motion parameters including seismic intensity, peak ground acceleration (PGA), response spectra and characteristic accelerograms. Analysis of observations and results of modeling allows re-constructing of the distribution of strong-motion parameters for the earthquakes of 1940 and 1977, for which the instrumental data are not available.

### NEW EMPIRICAL PREDICTIVE EQUATIONS FOR THE FOURIER AMPLITUDE SPECTRUM OF ACCELERATION AND ARIAS INTENSITY IN NEW ZEALAND – ID 820

*P. Stafford, University of Canterbury, New Zealand*
*J. Berrill, University of Canterbury, New Zealand*
*J. Pettinga, University of Canterbury, New Zealand*

Two new predictive models are introduced for application in New Zealand; one for the Fourier Amplitude Spectrum of strong ground motion acceleration, the other for Arias Intensity. Both measures of ground motion have large potential for application in engineering design scenarios, yet no models of this nature currently exist for use in New Zealand. The models are developed for ground motions from crustal earthquakes only and are presented as functions of moment magnitude and the shortest distance to the rupture surface. Allowance for the three standard New Zealand site class categories is made as well as for normal, strike-slip, and reverse/thrust fault mechanisms. The New Zealand strong motion dataset is supplemented with significant worldwide near-source

records. The functional forms of the models are governed by theoretical considerations which allow relatively comprehensive functional forms to be utilised. In particular, the model for the Arias Intensity includes theoretical terms to account for the scaling of the ground motion measure with both magnitude and distance. Random Effects models are implemented in order to obtain regression coefficients for both models. The general form of the Fourier Amplitude Spectrum of acceleration is modelled well over a wide range of frequencies of relevance to engineering design.

### WIDEBAND SIMULATION OF EARTHQUAKE GROUND MOTION BY A SPECTRUM-MATCHING, MULTIPLE-PULSE TECHNIQUE – ID 408

*A. Gusev, Institute of Volcanology and Seismology, Russian Federation*
*V. Pavlov, Kamchatka Branch, Geophysical Service, Russian Federation*

To simulate earthquake ground motion, we combine a multiple-point stochastic earthquake fault model and a suite of Green functions. Conceptually, our source model generalizes the classic one of Haskell (1966). At any time instant, slip occurs over a narrow strip that sweeps the fault area at a (spatially variable) velocity. This behavior defines seismic signals at lower frequencies (LF), and describes directivity effects. High-frequency (HF) behavior of source signal is defined by local slip history, assumed to be a short segment of pulsed noise. For calculations, this model is discretized as a grid of point subsources. Subsource moment rate time histories, in their LF part, are smooth pulses whose duration equals to the rise time. In their HF part, they are segments of non-Gaussian noise of similar duration. The spectral content of subsource time histories is adjusted so that the summary far-field signal follows certain predetermined spectral scaling law. The results of simulation depend on random seeds, and on particular values of such parameters as: stress drop; average and dispersion parameter for rupture velocity; rupture nucleation point; slip zone width/rise time, wavenumber-spectrum parameter defining final slip function; the degrees of non-Gaussianity for random slip rate in time, and for random final slip in space, and more. To calculate ground motion at a site, Green functions are calculated for each subsource-site pair, then convolved with subsource time functions and at last summed over subsources. The original Green function calculator for layered weakly inelastic medium is of discrete wavenumber kind, with no intrinsic limitations with respect to layer thickness or bandwidth. The simulation package can generate example motions, or used to study uncertainties of the predicted motion. As a test, realistic analogs of recorded motions in the epicentral zone of the 1994 Northridge, California earthquake were synthesized, and related uncertainties were estimated.

### THE HYBRID EMPIRICAL METHOD AND ITS USE IN PREDICTING STRONG GROUND MOTION IN EUROPE – ID 459

*K. Campbell, EQECAT, Inc., United States*

Ground motion prediction (attenuation) relations are used to estimate strong ground motion for many engineering and seismological applications. Where strong-motion recordings are abundant, these relations are developed empirically from strong-motion recordings. Where strong-motion recordings are sparse, these relations are often developed from seismological models using stochastic and theoretical methods. Although use of these latter methods has become common place, there is a large degree of uncertainty in calculating absolute values of ground motion from such methods in regions where data are sparse, especially at the larger magnitudes and closer distances of greatest importance in engineering. As an alternative, I have developed a hybrid empirical method (HEM) that uses the ratio of stochastic or theoretical ground-motion estimates between a target and host region to adjust empirical ground motion prediction relations available from the host region so that they can be used in the target region. By using empirical models as its basis, the HEM taps into the vast amount of observational data and expertise that has been used to develop empirical ground motion prediction relations in high-seismic areas with abundant strong-motion recordings, such as Western North America (WNA), Japan and the Mediterranean region. I present a formal mathematical framework for the HEM and demonstrate an example application of the method to the development of ground motion prediction relations for peak ground acceleration and acceleration response spectra in Eastern North America (ENA) using empirical relations from WNA. The application accounts for differences in stress drop, source properties, crustal attenuation, regional crustal structure, and generic rock profiles between the two regions. I will discuss the feasibility of using the HEM in Europe. The method is currently being applied in southern Spain and southern Norway by a team of European researchers.

## CS4-II: Strong Motion : Use and Modelling

Tuesday 10:45 - 12:15 – Room 2

### ISSUES RELATED TO THE TRUNCATION OF THE LOG-NORMAL DISTRIBUTION OF GROUND-MOTION RESIDUALS – ID 1084

*F. Strasser, Imperial College, UK*
*J. Bommer, Imperial College, UK*
*N. Abrahamson, PG&E, United States*

Recent studies to assess very long-term seismic hazard in the United States and in Europe have highlighted the importance of the upper tail of the ground-motion distribution at the very low annual frequencies of exceedance required by these projects. In particular, the use of an unbounded lognormal distribution to capture the aleatory variability of ground-motions leads to very high and potentially unphysical estimates of the hazard. Current practice in seismic hazard analysis consists in truncating the ground-motion distribution at a fixed number $\epsilon$max of standard deviations ($\sigma$), however, there is a general lack of consensus about the truncation level to adopt, with estimates ranging from $2\sigma$ to $4\sigma$.

This paper investigates whether a physical basis for choosing $\epsilon$max can be found, by examining records with large positive residuals from the dataset used in one of the ground-motion models derived during the New Generation Attenuation (NGA) project. In particular, interpretations of the selected records in terms of causative physical mechanisms are reviewed. This leads to the conclusion that even in well-documented cases, it is not possible to establish a robust correlation between specific mechanisms and large values of the residuals, and thus obtain direct physical constraints on $\epsilon$max. Alternative approaches based on absolute levels of ground motion and numerical simulations are discussed. However, the choice of $\epsilon$max is likely to remain a matter of statistical judgment for the foreseeable future, in view of the large epistemic uncertainties associated with these alternatives.

Additional issues arise from the coupling between $\epsilon$max and $\sigma$, which causes the truncation level in terms of absolute ground motion to be dependent on the predictive equation used. Furthermore, the absolute truncation level will also be affected if $\sigma$ is reduced significantly. These factors contribute to render a truncation scheme based on a single $\epsilon$max value impractical.

### A FIRST LOOK AT THE JUNE, 2000, M6.5 EARTHQUAKES IN ICELAND IN TERMS OF THE SPECIFIC BARRIER MODEL – ID 1133

*B. Halldorsson, Earthquake Engineering Research Centre, Iceland*
*S. Olafsson, Earthquake Engineering Research Centre, Iceland*
*R. Sigbjornsson, Earthquake Engineering Research Centre, Iceland*

The two M6.5 earthquakes that occurred in the populated South Iceland Seismic Zone (SISZ) on June 17 and 21, 2000, respectively, are the largest earthquakes to take place in Iceland since 1912 and for which high-quality strong motion data exists. The earthquakes thus provide a unique opportunity to revise

earthquake modeling, ground motion attenuation, and seismic hazard estimates in the area. We investigate the applicability of the recently calibrated Specific Barrier Model to predict the ground motions of the June 2000 earthquakes. We find that the local stress drop of the earthquakes is similar to that of other interplate earthquakes. However, the attenuation of seismic waves in the region is significantly greater than that in other interplate regions. We have calibrated the Specific Barrier Model to the three largest earthquakes in the SISZ by inverting for a new attenuation function. Recordings at sites in close proximity to the sources exhibited strong near-fault velocity pulses. For the first time, the characteristics of the recorded near-fault pulses have been identified in terms of a simple mathematical model of near-fault pulses and compared to the worldwide database of such records. The SBM and the near-fault pulse model combine naturally in a fast and efficient synthesis of realistic, broad-band strong ground motions in the far-field and near-fault region. We showcase the synthesis of such strong motions for the June 2000 earthquakes and estimate the quality of the fit of simulations to data. The broad-band simulations are shown to provide on the average unbiased predictions. The self-consistency and parsimonious nature of the specific barrier model, and the relationship to the parameters of the near-fault model, make them therefore the ideal tool for the fast and efficient broad-band simulation of strong ground motions for future events in the region.

### STRONG-MOTION SIMULATION USING A FREQUENCY-DEPENDENT RADIATION PATTERN CORRECTION – ID 1648

*R. Castro, CICESE, Mexico*
*F. Pacor, INGV, Italy*
*G. Franceschina, INGV, Italy*
*D. Bindi, INGV, Italy*
*L. Luzi, INGV, Italy*

Stochastic modeling techniques for finite faults (e.g. Beresnev and Atkinson, 1997) simulate the high-frequency ground-motion amplitudes by summing stochastic point sources. In this process is commonly assumed that the S-wave radiation pattern is independent of frequency and a constant average value is considered to model the source spectra. Recent studies of S-wave radiation pattern, using local earthquakes in Central Italy (Castro et al., 2006), show that at low frequencies (f<0.5 Hz) the observed radiation pattern is similar to that expected from a double-couple source. However, at higher frequencies (f>0.5 Hz) the S-wave radiation pattern vary randomly with frequency. In this study, we simulate strong motion records from the Umbria-Marche, Central Italy earthquake (Mw 6) of September 1997 using the frequency-dependent S-wave radiation function obtained by Castro et al. (2006). This function was obtained separating source and path effects from 22 local earthquakes, mostly with normal fault mechanisms, in consistence with the main earthquake modeled. We compare the observed acceleration spectra, from strong-motion instruments located in the near field and at regional distances, with those simulated using the stochastic modeling technique of Beresnev and Atkinson (1997,1998), modified to account for a frequency dependent radiation pattern correction. At station Nocera, located in the near field, site and directivity effects combined have a stronger influence on the observed acceleration spectra than the radiation pattern function. In general, we observed that although the frequency-dependent radiation pattern correction has a notable effect on the spectral amplitudes, the site effect is the most important factor controlling the strong-motion records generated by the 1997 Umbria-Marche earthquake.

### GROUND-MOTION PREDICTION IN PSHA: A POST-PEGASOS PERSPECTIVE – ID 1312

*F. Scherbaum, Universität Potsdam, Germany*
*J. Bommer, Imperial College London, UK*
*F. Cotton, Université Joseph Fourier, France*
*H. Bungum, 4) NORSAR/ICG, Norway*
*F. Sabetta, Servizio Sismico Nazionale, Italy*

The PEGASOS project in Switzerland has offered a unique opportunity to critically review the current state of ground motion prediction methodology in PSHA in particular for regions of low seismicity. Due to the common lack of empirical strong ground-motion data in such areas, it has become an accepted procedure to employ empirical ground-motion models from other regions, potentially with adjustments for differences between host and target regions. These models are usually based on rather different sets of predictor variables, which have to be adjusted as well. In systematically and rigorously applying the laws of uncertainty propagation to all of the required conversions and adjustments, however, a huge price has to be paid in an ever-growing aleatory variability. Once this path has been followed, these large sigma values will drive the hazard, particularly for low annual frequencies of exceedance. Therefore, the key issues in the context of ground-motion prediction for PSHA for the near future are to better understand the aleatory variability of ground motion and to develop suites of ground-motion prediction equations that employ the same parameter definitions. The latter is a global rather than a regional challenge which might be a desirable long-term goal for projects similar to the PEER NGA (Pacific Earthquake Engineering Research Center, Next Generation of Attenuation of Ground Motions) project.

### NEW STRONG GROUND-MOTION SPECTRAL ACCELERATION RELATIONS FOR THE HIMALAYAN REGION – ID 1459

*M. Sharma, IITR, India*
*H. Bungum, NORSAR, Norway*

New models for the ground-motion excitation and attenuation from earthquakes in the Himalayan region have been derived based on 175 strong-motion records from 12 Himalayan earthquakes since 1986, occurring over an EW distance range of more than 2000 km. The events are covering a moment magnitude range between 5.5 and 7.6 and a hypocentral distance range up to more than 200 km. Several of these records have been newly digitized and all have been reprocessed for this study, including a special analysis aimed at properly defining the horizontal component. The data base suffers from a lack of near-field recordings, however, which has been compensated by including additional data for distances less than 20 km from a global data set of reverse-faulting earthquakes. The Himalayan region poses special ground-motion estimation problems in terms of its complex tectonics and its wide range of focal depths, calling for careful considerations both of the functional form, which should be physically meaningful, and of the distance measure used. The inversion includes a separation between rock and soil conditions, and spectral ground-motion models have been developed for periods between 0.04 and 2.5 seconds.

### STRONG MOTION SIMULATIONS USING HYBRID 1D-3D VELOCITY MODELS AND CORRELATED SOURCE PARAMETERS – ID 1470

*R. Archuleta, University of California, Santa Barbara, United States*
*P. Liu, University of California, Santa Barbara, United States*
*S. Hartzell, US Geological Survey, United States*

We present a new method of calculating broadband time histories of ground motion based on a hybrid low-frequency, high-frequency approach. Low frequency synthetics are calculated using finite-difference in a 3D velocity structure; high-frequency synthetics are calculated using frequency-wavenumber integration in a 1D velocity model. The low and high-frequency components are combined with matched filtering at a cross-over frequency of 1Hz. The source description, common to both the 1D and 3D synthetics, is based on correlated random distributions for the slip amplitude, rupture velocity, and rise time on the fault. This source description allows for the specification of source parameters independent of any a priori inversion results. In addition, we include correlation coefficients between slip amplitude, rupture velocity, and rise time, as suggested by dynamic fault modeling. The method of using correlated random source parameters is very flexible and

can be easily modified to adjust to our changing understanding of earthquake ruptures. A common realistic attenuation model is used for both low and high-frequency synthetics where Q is based on the shear-wave velocity. In addition, to produce more accurate high-frequency amplitudes and durations, the 1D synthetics are corrected using a randomized, frequency-dependent radiation pattern. The 1D soil profile is based on generic NEHRP site classification. With this characterization the 1D synthetics are propagated through a nonlinear response using a time-domain, nonlinear, total stress calculation. The entire procedure is validated by comparison with the 1994 Northridge, CA, strong ground motion data set. The bias and error found here for response spectral acceleration is similar to the best results that have been published by others whose models depend on an initial description of the Northridge rupture.

## CS4-III: Strong Motion : Use and Modelling

Tuesday 13:30 - 15:00 – Room 2

### ON THE DISCREPANCY OF GROUND MOTION PREDICTIONS DERIVED FROM WEAK AND STRONG MOTION RECORDS – ID 1671

*G. Pousse, IRSN, France*
*F. Cotton, LGIT, France*
*F. Bonilla, IRSN, France*
*F. Scherbaum, Inst. Geowissenschaften, Germany*

Borehole rock Kik-net ground motion data (337 events, 3894 records) have been used to derive empirical ground motion models for various magnitude ranges. Our data analysis shows that ground motions from large earthquakes decay slower with distance than those from small earthquakes and that the magnitude scaling of the distance dependence decreases with magnitude. Using stochastic simulations, we show that such magnitude dependent decay is expected for response spectral values, even for a simple "point source" model in which stress drop is constant. Source properties of moderate and large earthquakes provide another way to explain differences in magnitude scaling properties. We discuss the pitfalls of deriving empirical prediction equations from recordings of small magnitude earthquakes and applying them for predictions of ground motion from larger events. Our results show that the use of a ground motion model outside the magnitude and distance range of the model-generating dataset depends on the chosen functional form. In addition, our data analysis shows that the aleatory variability is magnitude dependent. Our results provide a possible explanation for the overestimation of response spectral weak motion amplitudes when using empirical models derived from strong motion records. Such overestimation, as for example recently observed for several regions in Europe, does not necessarily imply regional differences of ground motion attenuation.

### STRONG GROUND MOTION IN SW IBERIA AND THE SOURCE OF THE 1755 LISBON EARTHQUAKE – ID 1803

*J. Borges, Centro de Geofísica de Évora - Univ. Évora, Portugal*
*R. Gradin, Centro de Geofísica de Évora - Univ. Évora, Portugal*
*M. Bezzeghoud, Centro de Geofísica de Évora - Univ. Évora, Portugal*
*B. Caldeira, Centro de Geofísica de Évora - Univ. Évora, Portugal*

On 1 November 1755 the city of Lisbon was struck by an earthquake which magnitude was evaluated to 8.5 (intensity XI-XII-MSK). The highest intensities were observed in Lisbon area and along the Algarve. It was felt all over Europe, north Morocco and Madeira Island. This event was accompanied by a massive tsunami, which was observed all over the North Atlantic coasts from Cornwall (UK) to North Morocco.The location of the source, responsible for the Lisbon tsunami, is not well known. There are a very large active structures located in the Atlantic margin, which were proposed as a good candidate for the generation of the 1775 event. Whoever the consensus about the responsible structure it is not yet achieved. Based on a 3D velocity model of the western Iberian margin and using a finite-difference seismic wave propagation code, we have calculated PGV for different rupture scenarios. After that, and using appropriated relations between seismic intensity (MMI) and PGV we have computed the synthetic isoseismic maps. By comparing these results with available seismic intensities it is possible to evaluate the realism of the different proposed sources. This study will give new insights on seismic risk in SW Iberia, and will help identify regions that are most exposed to strong ground motion in association with acknowledged fault rupture scenarios.

Reference: R. Grandin, J. F. Borges, B. Caldeira, M. Bezzeghoud, F. Carrilho and C. S. Oliveira, "Strong Ground Motion in SW Iberia due to adjacent oceanic earthquakes", poster presented at the E.G.Union General Assembly 2006, available at www.cge.uevora.pt.

### MW ESTIMATION FOR REGIONAL SEISMIC EVENTS IN THE FRIULI AREA (NE ITALY) – ID 1813

*P. Suhadolc, Dip. Scienze della Terra, University of Trieste, Italy*
*A. Valori, Dip. Scienze della Terra, University of Trieste, Italy*
*G. Costa, Dip. Scienze della Terra, University of Trieste, Italy*
*L. Moratto, Dip. Scienze della Terra, University of Trieste, Italy*

A stable and automatic method (Andrews, 1986) is implemented to estimate in real time the seismic moment (and Mw magnitude) based on broad-band velocimetric and accelerometric data (RAF 1993-2005) available in the Southern Alps area. The S phase is extracted applying both a manual picking procedure and an automatic method with traveltimes estimated from the knowledge of the hypocenter, recording site and structural model. The transversal component of motion is used to minimize conversion effects. The analysed frequency window is chosen on the basis of comparison between signal and noise spectra (S/R ratio). The source spectrum is obtained by correcting the signals for geometrical spreading and intrinsic attenuation. We compute source spectra for both velocity and displacement, and the seismic moment and the corner frequency are fitted (Andrews, 1986) assuming the Brune spectrum model. The real-time procedure is tested off-line with recordings of significant earthquakes in the area (Bovec 1998; Bovec 2004; Carnia 2002) and the results are in very good greement with seismic source moment estimations proposed by Harvard and MedNet.

### PARAMETRIC STUDIES FOR SCENARIO EARTHQUAKES: SOURCE-SITE EFFECTS AND DIFFERENTIAL MOTION – ID 1844

*F. Romanelli, Department of Earth Sciences, Italy*
*G. F. Panza, International Centre for Theoretical Physics, Italy*
*F. Vaccari, Department of Earth Sciences, Italy*

In sedimentary basins the generation of local surface waves and local resonance can give rise to a complicated pattern in the spatial groundshaking scenario. For any object of the built environment with dimensions greater than the characteristic length of the ground motion, different parts of its foundations can experience severe non-synchronous seismic input. In order to perform an accurate estimate of the site effects, and of differential motion, in realistic geometries it is necessary to make a parametric study that takes into account the complex combination of the source and propagation parameters. The simplified model of an extended seismic source we propose is based on the modelling of a Haskell-type source and contains a stochastic component, allowing to build a spectrum (amplitude and phase) of the source function that takes into account both the rupture process and directivity effects. In such a way it is possible to perform a speditive parametric study to investigate the dependence of the ground motion (in the time and frequency domain) on source parameters (geometry, energy release etc.). The computation of a wide set of time histories and spectral information, corresponding to possible

seismotectonic scenarios for different source and structural models, allows us the construction of damage scenarios that are out of reach of stochastic models. We show the numerical experiments carried out within the framework of several recent projects, to assess the importance of non-synchronousseismic excitation of long structures.

### THE FLING-STEP MOTIONS IN THE NEAR-FAULT RECORDS OF THE 1999 CHI-CHI, TAIWAN EARTHQUAKE – ID 1955

*H. C. Chiu, Institute of Earth Sciences, Academia Sinica, Taiwan*

Near-fault ground motions contain oscillating and fling-step motions. The former is due to the seismic radiation from a seismic source while the latter is associating with the permanent displacement of ground. The oscillating motions appear in all of the strong-motion records and its simulation is well developed in the past. Comparing to the oscillating motion, fling step is much less understood but being a very important component in the near-fault ground motions. Therefore, for a better prediction on the near-fault ground motions, we need improve our understanding the fling-step motions. Prior to the 1999 Chi-Chi Taiwan earthquake, very few strong-motion records near a surface rupture had been recorded. In the 1999 Chi-Chi, Taiwan earthquake, there are ten stations in the hanging-wall and about twenty footwall station had well recorded near-fault data. These recordings provide a great data set for studying fling-step motions. In this study, we analyze about twenty of these records. Results show that fling step motion has a major contribution (about 2/3) to the two large velocity impulses observed at TCU068 and TCU052. We also found that the ground motion caused by fling-step motion is much gentler and less spatial variation than that of the oscillating motions. These behaviors are quite different from that of the oscillating motions. Therefore, the prediction of fling-step motions should be based on a different approach. Although the number of near-fault data is still too small to develop a predictive model for fling-step motions, the Chi-Chi data did a much improvement on our understanding of near-fault ground motions.

### A COMPARATIVE ANALYSIS OF RECORDED STRONG GROUND MOTION IN THE AZORES AND ICELAND – ID 1164

*C. Oliveira, Instituto Superior Tecnico, Portugal*
*R. Sigbjörnsson, University of Iceland, Iceland*
*S. Ólafsson, University of Iceland, Iceland*

This paper presents the main results of a comparative study of recorded strong ground motion on the Azores and Iceland. The tectonic environments are outlined and compared emphasising the similarities in the geological structure, including surface geology and its effects on strong ground motion. Furthermore, the seismicity of the Azores and Iceland is compared based on earthquake catalogues using statistical analysis. The strong motion networks on the islands are described along with the strong motion data used in the subsequent analysis. The strong motion data are compared using statistical analysis, including t-test and analysis of variance. The main emphasis is put on attenuation of strong motion data, characterised by root mean square acceleration, peak ground acceleration, Arias intensity, duration and response spectral ordinates for selected natural periods and critical damping ratios. Furthermore, the shape of response spectra is dealt with. The attenuation is also compared to some of the common attenuation relationships, used by the engineering community in Europe. The main findings are that there are significant similarities between the tectonic environments of the Azores and Iceland. Furthermore, the similarities found in seismicity are statistically significant. The attenuation is characterised by rapid decay with increasing distance from site to source and high acceleration in the near source area. It is found that the same attenuation relationship can be applied on the Azores and in Iceland. On the other hand, it is found that fitting of some of the commonly used attenuation relationships to the data is not statistically significant. The deviation is most apparent for large epicentral distances. The findings of this study indicate that there may be significant regional differences in strong ground motion related to the tectonic environments and local geology, namely in volcanic environments.

## CS4-IV: Strong Motion : Use and Modelling

Tuesday 15:30 - 17:00 – Room 2

### SITE-SPECIFIC HF ENVELOPES AND THE STOCHASTIC GREEN FUNCTION SIMULATION OF STRONG GROUND MOTIONS – ID 751

*A. Petukhin, Geo-Research Institute, Japan*
*T. Kagawa, Geo-Research Institute, Japan*
*M. Tsurugi, Geo-Research Institute, Japan*

Complex ground conditions under/around a target site cause both amplification due to the effect of soft layers and an increase of duration due to the scattering. Spectral ratio methods are developed in different modifications to account for the amplification effect. Effect of the scattering is less well understood. In this study we propose a semi-empirical method of the estimation of the site-specific frequency dependent envelopes. To do this we assumed that the high-frequency envelope at a site could be represented as a convolution of source, path and site envelopes. For records of small earthquakes (Green's functions) source envelope is the delta-function. Path envelope can be estimated as the envelope at a reference site or by the generalization of observed envelopes at rock sites. Then, site envelope is estimated by the deconvolution of the bedrock site envelope from the observed envelopes separately for each of the 4 octave frequency bands: 1-2, 2-4, 4-8 and 8-16 Hz. This approach can be proved by the analysis of the residues between observed and simulated envelopes; they don't have any trend.

Using developed methodology we estimated the HF site envelopes at the 4 soft-soil sites of the CEORKA network in the Osaka basin, Japan: FKS, SRK, TDO and YAE. As expected, due to the basin waves generation, envelopes are much longer in the lowest frequency band than in a higher frequency bands. Then, they were used to simulate HF strong ground motions during the Nankai-Tonankai earthquake using the stochastic Green's function method. Combined with the effect of the long rupture propagation in the source of this giant earthquake, this method produces a realistic long-duration strong ground motions. Moreover, these waveforms are free of the unrealistic holes in the amplitudes due to the rupture propagation in the inter-asperity regions, which strongly change the response of the nonlinear structures.

### TORSIONAL RESPONSE INDUCED BY VRANCEA EARTHQUAKE GROUND MOTIONS – ID 658

*R. G. Enache, Technical University of Civil Engineering, Romania*
*S. Demetriu, Technical University of Civil Engineering, Romania*
*E. F. Albota, Technical University of Civil Engineering, Romania*

The ground motion during an earthquake includes translational and rotational components. The rotation about horizontal axes gives rise to rocking, while the rotational component about a vertical axis generates torsional effects even in symmetrical buildings. This paper deals with the rotational components about a vertical axis. The angular acceleration, velocity and displacement time histories are obtained from the translational acceleration and velocity on two horizontal orthogonal directions, recorded during 1977, 1986 and 1990 Vrancea earthquakes for different site conditions. The torsional response spectra for these sites and the average normalized torsional spectrum for Bucharest are computed. The influence of the rotational components on the elastic seismic response is analysed for symmetrical and for non-symmetrical systems. The study is made on systems with different eccentricities and stiffnesses, considering simultaneously the recorded translational components and the computed rotational component of the earthquake ground motion.

### 3-D GROUND MOTION MODELING IN THE ADAPAZARI BASIN, USING THE 3D STRUCTURE ESTIMATED BY MICROTREMORS – ID 923

*S. Tsuno, Earthquake Research Institute, the Univ. of Tokyo, Japan*
*K. Kudo, Earthquake Research Institute, the Univ. of Tokyo, Japan*
*J. Bielak, Dept. of Civil and Environmental Eng., CMU Univ., United States*

The 3D S-wave velocity model in the Adapazari basin is estimated by integrating the inversion results of phase velocity dispersion and ellipticity of Rayleigh waves included in microtremors [Tsuno et al., 2006]. We could well reproduce the early S-wave arrivals of the ground motion from the largest aftershock of September 13 (M5.8) at the sediment sites, using 1D analysis with the horizontal layer model. On the other hand, the later arrivals could not be modeled by 1D wave propagation. We, therefore, should model the aftershock ground motion using the 3D basin structure estimated by micorotremors.

The finite element method (FEM) [Bao et al., 1998] is applied for the 3D ground motion modeling in the Adapazari basin. We modeled a region of 96km (east-west) x 96km (north-south) x 55 km (depth), which includes the source and the Adapazari basin; the epicentral distances from the basin are within 30 km. The element sizes vary from 80 m to 640 m associated with the corresponding S-wave velocity. The upper frequency of our interest is limited to 0.7 Hz, due to the low velocity ( 570 m/s) of the surface layers in the Adapazari basin. We used a flat crustal structure model for the region outside the basin (25 km x 25 km) and constrained the source model by Yamanaka and Kikuchi (EIC Seismological Note). We got acceptable agreement between the simulations and the observations at SKR and IZT, which are located on rock outcrop and in different azimuth.

Two point sources, at depth of 8 km and 3 km, give reasonable agreement of waveforms between simulations and observations especially at sediment sites. The ground motions and response spectra (h=5%) synthesized by hybrid method combining between 1D analysis and 3D simulation, match well throughout broadband frequency (0.1-10Hz) with the observations in the Adapazari basin.

### GROUND MOTION MODELS FOR MOLISE REGION (SOUTHERN ITALY) – ID 938

*L. Luzi, INGV, Italy*
*P. Morasca, DIPTERIS, Italy*
*F. Zolezzi, DIPTERIS, Italy*
*D. Bindi, INGV, Italy*
*F. Pacor, INGV, Italy*
*G. Ferretti, DIPTERIS, Italy*
*D. Spallarossa, DIPTERIS, Italy*
*G. Franceschina, INGV, Italy*

On October 31st and November 1st, 2002 two moderate earthquakes of magnitude Mw=5.7 (INGV-Harvard European-Mediterranean Regional Centroid-Moment tensor project) occurred in southern Italy. After the mainshocks, felt in many municipalities of the Molise and Puglia region, a strong motion and seismic temporary network were installed in the epicentral area and surrounding regions. The strong motion network was composed by 9 stations, integrating the accelerometers of the permanent Rete Accelerometrica Nazionale (RAN network), and operated until December 2003. The strong motion data set is composed by 195 recordings from 51 earthquakes (2.5<Ml<5.4) recorded by 29 accelerometers (DPC-USSN, 2004). In addition to the strong motion network, several Italian research institutions (Istituto Nazionale di Geofisica e Vulcanologia, INGV; Istituto Nazionale di Oceanografia e Geofisica, INOGS; Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Dip.Te.Ris) participated in the installation of a temporary regional network, composed by 35 seismic stations. This network aimed at monitoring and studying the time and spatial evolution of the seismic sequence. More than 1900 aftershocks in the local magnitude range 2-4.2 were recorded in the period November 1st - December 5th, 2002 (Chiarabba et al., 2005). The unified velocity-acceleration data set has been considered to derive ground motion models for peak ground acceleration, peak ground velocity and 5%-damped pseudo-velocity response spectra, for both maximum horizontal and vertical components. The random effect model (Brillinger and Priesler, 1985; Abrahamson and Youngs, 1992) has been applied to estimate the inter- and intra- event component of variance, while the uncertainties affecting the regression coefficients have been estimated via a bootstrap analysis (Efron, 1979). Finally, we applied the maximum likelihood approach recently proposed by Scherbaum et al. (2004) to measure the goodness of fit for several ground motion models applied to predict the Molise strong ground motion parameters.

### STRONG GROUND MOTION PREDICTION WITH MULTI-SCALE HETEROGENEOUS SOURCE MODELS FOR HUGE SUBDUCTION-ZONE EARTHQUAKES ALONG THE NANKAI TROUGH, JAPAN – ID 1044

*M. Yoshimi, Geological Survey of Japan, AIST, Japan*
*H. Sekiguchi, Geological Survey of Japan, AIST, Japan*

The Nankai trough, lying along southern coast of the main island of Japan, is the place where next giant earthquakes are anticipated. For preparation for those earthquakes, it is very important to estimate ground motions as realistic as possible. In this study, we simulate strong ground motions from anticipated Nankai earthquake by a finite-difference technique [Pitarka, 1999] with multi-scale heterogeneous rupture models and with realistic 3D subsurface structure model, focusing on densely populated area of the Osaka sedimentary basin about 200 km north of the Nankai trough. We develop rupture models for a future Nankai earthquake from a model published by the Central Disaster Mitigation Council in Japan [2003]. Main modifications we make are as follows: 1) Fault surfaces are refined and fit to complexly curved upper surface of the subducting plate. 2) Slip distributions are transformed hierarchically to obey k-1.75 spectrum, average heterogeneity derived from source inversion results [Mai & Beroza, 2003], and rupture velocities are also fluctuated making source spectra of resultant rupture models obey omega-square spectrum. 3) A slip-velocity function based on dynamic rupture simulation [Nakamura & Miyatake, 2000] is assumed. Our 3D subsurface structure model is composed of Osaka sedimentary basin, crust, upper mantle, subducting slab, and accretionary prism. The dimension of the model is horizontally about 400km x 350 km and about 100 km in depth. Simulated ground motions on the Osaka basin are characterized as long period, prolonged, and amplified motions. We found that both the accetionary prism and the Osaka sedimentary basin structure play important roles in producing such ground motions. And also we found that amplitudes of ground motions vary with rupture models.

### CHARACTERISTICS OF ROCKING GROUND MOTION USING CHIBA DENSE ARRAY DATA – ID 1056

*M. Ghayamghamian, IIEES, Iran (Islamic Republic Of)*
*G. Nouri, IIEES, Iran (Islamic Republic Of)*

The ground motions produced by earthquakes can be completely described by six components of translation and rotation. The rotational components are usually neglected, one of the reasons being the lack of reliable data on rotational ground motion. Several studies have shown the importance of these ignored components in the seismic analysis and design of structures. In particular, the rocking component is shown to be very important in the analysis of tall and rigid structures. Seismographs are generally installed more than several kilometers apart from each other. These distances are too long to reliably identify the rotational components. The seismic dense array observation is a powerful tool to investigate the various characteristics of rocking component of earthquake strong ground motion. Three-dimensional dense array at Chiba, located about 30km east of Tokyo, includes 44 three-component accelerometers providing unique set of data for the research on the properties of rocking ground motion. In this study a set of data,

including 17 events are considered and the rocking component is evaluated for pairs of accelerometers in different distances for each event. Then, the relation between rocking ground motion and seismological parameters such as magnitude, PGA, distance and duration are investigated. It is observed that the frequency content of rocking ground motion obtained from the close stations are very different from those evaluated from distant ones. Besides, the ratio of response spectra of rocking to vertical components do not follow a linear pattern.

## CS5-I: Site Response and Site Effects

Wednesday 10:45 - 12:15 – Room 1

### USING AMBIENT NOISE ARRAY TECHNIQUES FOR SITE CHARACTERISATION: RESULTS FROM AN INTERNATIONAL BENCHMARK – ID 2032

*C. Cornou, LGIT, France*
*M. Ohrnberger, IGUP, Germany*
*D. Boore, USGS, United States*
*K. Kudo, ERI, Japan*
*P. Y. Bard, LGIT, France*

It is well known that unfavourable site conditions may give rise to significant local amplification of ground motion during earthquakes. Thus, there is a need to carry out site-specific studies for allowing an efficient mitigation of seismic risk through both site classification and numerical prediction studies. Most important for characterizing site effects, either by quantifying Vs30 or by forward modeling of frequency dependent amplification effects, is a proper knowledge of the shallow and sometimes deep shear wave velocity structure. Originally proposed by Japenese authors, the use of array measurements applied to ambient vibration for estimating the subsurface S-waves velocity has spread throughout the world in recent decades. Although processing techniques - mainly f-k based and SPAC techniques - have improved and the limitations of various methods for extracting velocity models from measurements of microtremors are better understood, the combined influence of site structure, ambient vibration source characteristics on the observable microtremor wavefield itself is less clear. It is therefore important to have a completely independent check of the reliability of results and their related uncertainties. Within the third international symposium on Effects of Surface Geology on seismic motion, a noise blind test was thus organized in order to compare results from competing analysis approaches and make more definitive assessments regarding the potential of microtremor array studies for site effect esimation. This blind test involved both synthetic and real data sets. Synthetic data provided benchmark test where the site structure and the wavefield situation are fully known. Real sites were used to properly assess the reliability of results for various real site conditions. Around 15 groups participated to this exercise using different techniques. We report here the results of this exercise and outline the key issues that should be addressed in the future for improving the estimation of shear profiles.

### GENETIC AND LINEARIZED ALGORITHMS FOR THE JOINT INVERSION OF RAYLEIGH WAVE DISPERSION CURVES AND H/V SPECTRAL RATIOS FROM ENVIRONMENTAL NOISE RECORDINGS: A CASE STUDY IN THE PO RIVER VALLEY (NORTHERN ITALY) – ID 1707

*M. Picozzi, University of Siena, Italy*
*D. Albarello, University of Siena, Italy*

The joint inversion of Rayleigh wave dispersion and H/V curves from environmental noise measurements allows retrieving S-wave velocity profiles in the shallow subsoil. In this work two inversion procedures, respectively based on Linearized and Genetic algorithm, have been compared. To this purpose, seismic noise recordings at a test site in the Po river valley (North Italy) have been analyzed. Here, detailed geophysical and geological information are available along with earthquake recordings, which allow a well constrained definition of the local shear wave profile and local transfer function. Both the inversion strategies reveal to be effective. However, parameterizations provided by Genetic algorithm are not necessarily optimal. On the other hand, Linearized inversion algorithm require initial guess values for the unknown parameters that must be relatively near to the final solution to warrant the convergence towards the optimal values. It has been shown that at the test site, the best performing inversion strategy has implied two steps. At first, genetic algorithm procedure have been used to constrain the volume of the parameters space where the absolute minimum of the misfit function is located. At second, a linearized inversion algorithm, having the minimum misfit model deduced form the first step as an initial guess, has been applied to drive the inversion towards the optimal solution. Comparison between theoretical and experimental S-wave velocity profiles and, above all, between theoretical and experimental site response functions show that this combination of inversion procedures can be very effective to manage the extreme non linearity of the problem.

### IN SITU MEASUREMENTS OF DAMPING RATIO FROM ENVIRONMENTAL NOISE MEASUREMENTS – ID 1928

*D. Albarello, Dip. di Scienze della Terra - Università di Siena, Italy*
*F. Baliva, Dip. di Scienze della Terra - Università di Siena, Italy*

Damping ratio of the shallow subsoil represents an important parameter that controls the amplification of input seismic motion. This is usually measured on laboratory specimens, but the effect of sample disturbance is uncertain and the frequencies used in laboratory tests are usually one to two orders of magnitude higher than those of interest in earthquake engineering. An alternative approach is to use field measurements to provide in-situ estimates. Some attempts in this direction have been performed by the direct measurement of body waves attenuation in the frame of crosshole or downhole configurations. In alternative, to overcome the severe drawbacks of this approach, it has been proposed to measure attenuation of surface waves by using standard SASW or MASW approaches. In this work, an attempt is made to retrieve damping ratio from environmental noise measurements in array configurations. It is well known that phase velocities of surface waves can be obtained in this way by using a number of techniques (ESAC, F-K, etc.). However, much more difficult it appears the problem to evaluate attenuation properties. In particular, the role of geometrical spreading cannot be easily accounted for when uncontrolled distributed sources are of concern. However, theoretical results on the properties of diffuse wavefields, corroborated by laboratory and field experiments, show that by cross-correlating noise measurements carried on at two sites, the Green functions relative to surface waves propagating from one site to the other can be retrieved. By following this approach, a numerical procedure has been provided to estimate damping ratios from environmental noise measurements carried on at an array of standard vertical geophones. Encouraging results have been obtained at two test sites where independent in-situ estimates of damping ratio in the shallow subsoil is available.

### MICROTREMOR ARRAY MEASUREMENTS IN NORTHERN BUCHAREST FOR ESTIMATION OF SITE RESPONSE – ID 486

*A. Aldea, UTCB/NCSRR, Romania*
*H. Yamanaka, Tokyo Institute of Technology, Japan*
*T. Takahashi, Tokyo Soil, Japan*

The Capital of Romania, Bucharest, is exposed to strong earthquakes from Vrancea subcrustal seismic source. Bucharest is located on about 1000m of sediments that partially explain the long period seismic motions observed during the March 4, 1977 (Mw=7.5) and August 30, 1986 (Mw=7.2) events. The Bucharest 1977 record obtained at INCERC seismic station firstly displayed an acceleration response spectra with important amplifications

at long periods (1÷2s) and attracted international attention: "It is indeed fortunate that at least one reliable observation of the ground motion was made in Bucharest. It appears to be a very interesting one which may modify the concepts of standard response spectra." (EERI, 1977). Even some geological data are available for the description of site conditions, there is an important need for knowing the soil properties at larger depths. Array microtremor measurements are nowadays a popular method for identifying the shear wave velocity profile at a site. In the frame of the Japan International Cooperation Agency seismic risk reduction Project in Romania, Japanese experts together with staff of the National Center for Seismic Risk Reduction, Bucharest, performed array microtremor measurements at three sites in the northern half of Bucharest. A first set of measurements was done in 2004 (recording pattern and data analysis according to SPAC methodology), and a second in 2005 (recording pattern and data analysis according to F-K methodology). Both sets of measurements contained small, medium and large size arrays, with station-to-station distances up to about 1.5 km. The obtained phase-velocities were then inverted by a genetic-algorithm methodology (Yamanaka and Ishida, 1996). The paper presents the array microtremor measurements, the inversion of phase velocities by genetic algorithms, the resulting shear wave velocity profiles for the three sites and a discussion on the site-response based on these profiles.

### RELATIONS BETWEEN STRONG GROUND MOTIONS AND MICROTREMORS BY AN ARRAY OBSERVATION SYSTEM – ID 255

*M. Kamiyama, Tohoku Institute of Technology, Japan*

The purpose of this paper is to compare spectral characteristics of strong ground motions and microtremors using records obtained at 20 sites of an array observation system. The array observation system is situated in Sendai City, Japan. The system, named Small-Titan, consists of 20 observation stations with various soil conditions. Since the installation in 1998, it has observed more than 400 earthquake-records. Using these records, the author estimated statistically spectral amplification factors in the horizontal and vertical components, respectively, at each observation site. These spectral amplification factors in both directions are quite different depending on the local soil condition of each site. Microtremors were also observed at all the observation sites. The so-called H/V spectrum, which is the spectral ratio of the horizontal component to the vertical one, is a key parameter reflecting the amplification of microtremors, so I analyzed them at each observation site. Comparisons between the statistical amplification factors of strong motions and H/V spectra of microtremors showed that the horizontal amplification factors have strong similarity in spectral shape against the H/V spectra of microtremors whereas the vertical ones are different from the H/V characteristics. Although such highly similar shape of spectra was found for the horizontal strong-motions and microtremors, the absolute spectral amplitudes in both ones indicated a difference in level, revealing some remarkable offsets of spectral amplitude that are independent of period. Based on the comparisons, fitting analyses between the horizontal spectral amplification factors and H/V spectra of microtremors were made to obtain an optimal parameter of offset for the H/V spectra of microtremors. This paper finally concludes that microtremors are useful to obtain amplification factors due to local soil condition with aid of an offset method of their H/V spectral amplitudes.

### SITE-CITY INTERACTION: BENEFICIAL OR DETRIMENTAL EFFECTS ? – ID 1295

*J. F. Semblat, LCPC, France*
*M. Kham, EDF R&D, France*
*P. Y. Bard, LCPC/LGIT, France*

The geometrical and mechanical features of surface soil layers have a major influence on seismic site effects. However, for alluvial basin located in densely urbanized areas, the surface structures such as buildings could influence seismic wave propagation at the free surface. Furthermore, the vibration of a surface structure can generate a seismic wave field into the soil. In this paper, the influence of surface structures on seismic site effects is analyzed numerically in the case of an alluvial basin. Two cases are considered: a simplified model with a nearly 1D soil configuration and an actual shallow basin profile (center of Nice, France). At a local scale, the vibration of a surface construction can induce a seismic wave field in the surficial soil layers. At the scale of an alluvial basin, the site-city models considered herein show that the city effect can lead to a significant seismic wave field modification when compared to the free-field case. The coincidence between the fundamental frequencies of the soil layers and eigen frequencies of the surface structures is a key parameter to investigate site-city interaction. When comparing the simplified city model to the basin-city model, the influence of the lateral heterogeneities on the site-city interaction is found to be significant since the seismic wave field radiated by the city appears to be trapped within the alluvial basin. The effects of the site-city interaction are thus beneficial in some parts of the city or detrimental in other parts and they also depend on the urban configuration (boundary effects, building density contrast...). Finally, the full characterization of the seismic wave field in densely urbanized areas could often raise the need for investigations on the site-city interaction depending on such parameters as: basin and city fundamental frequencies, building density, city arrangement as well as basin effects.

## CS5-II: Site Response and Site Effects

Wednesday 13:30 - 15:00 – Room 1

### AGGRAVATION OF SEISMIC GROUND MOTION DUE TO SLOPE TOPOGRAPHY – ID 1171

*A. Papadimitriou, National Technical University of Athens, Greece*
*G. Bouckovalas, National Technical University of Athens, Greece*

This paper presents results of numerical analyses for the seismic response of step-like ground slopes in uniform visco-elastic soil, under vertically propagating SV seismic waves. The aim of the analyses is to explore the effects of slope geometry, predominant excitation frequency and duration, as well as dynamic soil properties on seismic ground motion in a parametric manner, and provide qualitative as well as quantitative insight to the phenomenon. Among the main conclusions of this study is that this kind of topography may lead to intense amplification or de-amplification variability at neighboring (within a few tens of meters) points behind the crest of the slope, especially for high frequency excitations. Nevertheless, a general trend of amplification near the crest and de-amplification near the toe of the slope seems to hold for the horizontal motion. As a result of these two findings, it becomes evident that reliable field evidence of slope topography aggravation is extremely difficult to establish. Furthermore, this study highlights the generation of a parasitic vertical component of motion in the vicinity of the slope, due to wave reflections at the slope surface, that under certain preconditions may become as large as the horizontal. Criteria are established for deciding on the importance of topography effects, while approximate relations are provided for the preliminary evaluation of the topographic aggravation of seismic ground motion and the width of the affected zone behind the crest.

### EXPERIMENTAL AND NUMERICAL STUDY: EFFECTS OF SURFACE - SUBSURFACE TOPOGRAPHY ON STRONG GROUND MOTION – ID 1163

*O. J. Ktenidou, Aristotle University of Thessaloniki, Greece*
*K. Pitilakis, Aristotle University of Thessaloniki, Greece*
*D. Raptakis, Aristotle University of Thessaloniki, Greece*
*P. Apostolidis, Aristotle University of Thessaloniki, Greece*
*K. Makropoulos, National Kapodistrian University of Athens, Greece*
*D. Diagourtas, National Kapodistrian University of Athens, Greece*

The aim of this paper is to study the effects of surface and subsurface topography on strong ground motion using 2D numerical analysis as well as processing recordings from earthquakes and microtremor measurements. The site chosen for this study is Aegion, Greece, a highly seismic area marked by a characteristic morphology, with the Aegion Fault dividing the city into two levels with a 40m-100m escarpment. This site possesses the advantage of a permanent downhole array (at several depths and at the surface) operating almost constantly since 2002 (CORSSA: CORinth Soft Soil Array) in conjunction with certain other surface stations. Another advantage is that the geometry, the surface geology and the soil parameters are relatively well constrained. A detailed 2D soil model crossing the fault and comprising both levels of the area was recently constructed, based on in situ and laboratory geotechnical tests, geophysical prospecting and microtremor measurements. This paper presents some numerical modelling and dynamic 2D analysis of the city cross-section performed both on a simplified and on a more detailed model, using synthetic pulses as well as actual recordings at 'rock' level. Parametric analyses are performed, resulting in complex wave fields governed by 2D phenomena in the vicinity of the crest and toe, which cannot be explained by 1D analysis and are due both to the topographic relief and the lateral discontinuities. Numerical results are compared to experimental data both uphill and downhill, in the time and frequency domain, contributing to a better understanding of the complex phenomena occurring, bearing seismic design codes in mind.

### 2D WAVE PROPAGATION AT THE ORVIETO CLIFF FOR THE INVESTIGATION OF SOIL AND TOPOGRAPHY EFFECTS – ID 809

*G. Lanzo, University of Rome La Sapienza, Italy*
*A. Pagliaroli, University of Rome La Sapienza, Italy*
*P. Tommasi, National Research Council, Italy*

It is well recognised that local seismic effects can exert a significant influence on the distribution of ground motion and damages during earthquakes. Site effects include "stratigraphic effects" related to the impedance contrast between surface soil deposits and the underlying bedrock, and "topographic effects" due to surface topography. A typical geo-morphological feature, especially widespread in southern and central Italy, is constituted by isolated cliffs, formed by rock buttes overlying a more deformable clayey substratum, on top of which several historical towns are constructed. For this cliff-like morphology both stratigraphic and topographic effects can be equally important in assessing the seismic response, especially at the margin of the rock slab where even a moderate increase of the seismic action can significantly affect the stability conditions. In this context, the historical town of Orvieto located in Central Italy is considered. Orvieto rises on top of a pyroclastic rock butte overlying an overconsolidated clay formation. The slab is not homogeneous but is formed by a weakly cemented tuff ("pozzolana") overlying a competent tuff. Two-dimensional finite-different analyses are conducted using Ricker wavelets of different central frequencies applied as vertical incident SV waves. Both homogeneous and heterogeneous models are considered in order to clarify the influence of impedance contrast and surface geometry on the wave-field. The role played by stratigraphy was ascertained by performing 1D additional analyses at the center of the cliff. The uncoupling between the stratigraphic and topographic affect has been attempted via the Topographic Aggravation Factor (TAF), defined as the 2D over 1D smoothed Fourier spectra. In particular the conditions at the crest of the cliff are analysed and discussed in detail.

### ANALYSIS OF DEEP VALLEY RESPONSE BY AMBIENT NOISE, EARTHQUAKE RECORDS AND NUMERICAL SIMULATIONS – ID 1108

*D. Roten, ETH, Switzerland*
*D. Fäh, ETH, Switzerland*
*D. Giardini, ETH, Switzerland*

The impact of local ground motion amplification on earthquake damage was demonstrated during many recent damaging earthquakes. In deep sediment-filled Alpine valleys, effects such as edge-generated surface waves or global resonances may cause even higher amplifications due to the complicated 3-D basin structure.

In the framework of the SHAKE-VAL project, we are investigating the response of the Rhône valley, a deep sedimentary basin in Southern Switzerland. We recorded the ambient vibration wavefield on linear and circular arrays at different sites in the Rhône valley. Application of the site-to-reference spectral ratio method to these noise records shows that 2-D resonance dominates the noise wavefield at low frequencies, and allows the identification of the fundamental mode 2-D resonance frequencies SH00 and SV0. Because of the strong non-1D structure of the site, standard inversion techniques fail to invert dispersion curves derived from f-k analysis for the shear-wave velocities of the deeper structure. We introduce an approach to derive shear-wave velocities of the sediment fill in a combined inversion of 2-D resonance frequencies and apparent Rayleigh wave phase velocities. This inversion method yields velocity models that are consistent with all observations.

The obtained shear-wave velocities are used to create a local 3-D velocity model of the Sion area, which serves as input for numerical simulations of strong ground motion with the finite difference technique. Together with local earthquake records acquired on a dense temporary array, we analyse these synthetic waveforms with the reference station method and frequency-wavenumber techniques to determine the amount of amplification and to study effects of wave propagation in the Rhône basin.

### MITIGATION OF THE SEISMIC MOTION APPLIED NEAR SLOPING GROUND DURING THE 1995 AEGION EARTHQUAKE – ID 1028

*C. Stamatopoulos, Stamatopoulos and Associates Co, Greece*
*M. Bassanou, Stamatopoulos and Associates Co, Greece*

During the 1995 Aegion earthquake, many buildings near the edge of the Aegion slope suffered serious damage presumably as a result of amplification of the acceleration near the crest of the slope. The effect of two methods mitigating this damage were studied numerically.

The first method consisted of adding anchors at the top of the slope with inclination of about 60 degrees to the horizontal. The concept is to connect the region near the edge and the top to the region at some depth and far from the edge where the acceleration is less. In this manner, the whole body connected with anchors will move as one block. Thus, the acceleration at the top and near the edge will decrease. The second mitigation method consisted of a soft horizontal layer at a depth of about 10m and slightly inclined to prevent static failure. The concept of this method is to mitigate the large seismic motion applied near the tip of the slope by allowing controlled failure and relative displacement at some depth.

Dynamic elasto-plastic analysis was performed using the FLAC computer code. A strain-hardening elasto-plastic model was used. Anchors were simulated using structural elements. Without mitigation, the role that topography played on the amplification of the acceleration and some ground settlement near the crest of the slope were observed. With the first mitigation method, the seismic motion applied near the toe of the slope decreases to the levels of the 1-D case, thus eliminating the topographic amplification effect. With the second mitigation method, the applied acceleration near the toe decreases to values less than the 1-D case.

### THEORETICAL EVIDENCE FOR INCREASES OF DURATION AND AMPLIFICATION OF PEAK EARTHQUAKE GROUND MOTION AT SITES WITH NON-PLANAR STRESS-FREE SURFACES – ID 1330

*A. Wirgin, LMA/CNRS, France*
*J. P. Groby, LATF/KU Leuven, Belgium*

A question of some importance in seismology, civil engineering, urban planning, and natural disaster risk assessment, is to what extent surface topography of different length and height scales (ranging from those of mountains and hills to city blocks and buildings) modifies the seismic response on the ground. There exists

experimental evidence that this modification is real and can attain considerable proportions as regards increases in peak ground motion and signal duration. Some theoretical studies seem to indicate that such effects are indeed possible, but various numerical studies yield conflicting results in that some of these point to amplification, while others to very weak effects, or even to de-amplification. Conflicting results are also obtained regarding the duration of the earthquakes at sites with uneven stress-free surfaces.

We provide a theoretical analysis which supports the conclusion that such substantial deleterious effects can, and will, indeed occur repeatedly if the irregularity of the ground is spatially-periodic (as often occurs in portions of modern cities and in various geological formations).

## CS5-III: Site Response and Site Effects

Thursday 10:45 - 12:15 – Room 1

### SITE EFFECTS ESTIMATION USING EARTHQUAKE AND AMBIENT NOISE DATA: THE CASE OF LEFKAS TOWN (W. GREECE) – ID 1249

*P. Triantaffylidis, Inst. of Eng. Seismology & EQ Eng. Thessalonik, Greece*
*N. Theodulidis, Inst. of Eng. Seismology & EQ Eng. Thessalonik, Greece*
*A. Savvaidis, Inst. of Eng. Seismology & EQ Eng. Thessalonik, Greece*
*P. Dimitriu, Inst. of Eng. Seismology & EQ Eng. Thessalonik, Greece*

The town of Lefkas is assigned zone III in the current Greek seismic code and has been repeatedly hit in the past by strong nearby earthquakes, the last one occurring on August 14th, 2003 (M6.2). An accelerograph was installed almost thirty years ago in the town of Lefkas, and several recordings with peak ground acceleration, PGA>0.1g, have been acquired permitting a thorough investigation of non-linear soil behaviour. This consists the strong motion data set. After the last strong earthquake, four digital, high-resolution accelerographs were installed at selected soil sites of the town and one at a reference "rock" site. During three months of continuous operation, this array recorded several hundreds of aftershocks, providing a large dataset suitable for the study of site effects in the town of Lefkas. This dataset consists mainly of low-amplitude recordings (PGA<0.05g) and represents the weak-motion dataset. In the aforementioned strong-motion station sites, single-station ambient-noise measurements were performed using broadband sensors with high-resolution digitisers. These measurements constitute the ambient-noise dataset. We processed the recordings from the three datasets by applying the SESAME-software and a common procedure. First, at all soil sites we evaluated the standard spectral ratio (SSR) and horizontal-to-vertical component spectral ratio (HVSR) using the weak-motion dataset. Then we computed the HVSR at those sites where strong- motion data were available. Finally, we used ambient-noise data to estimate HVSR at all stations. Comparison between SSR and HVSR from both earthquake and ambient noise data reveals similarity in the evaluated fundamental frequencies and striking differences in their amplitudes, in agreement with previous results. At some soil sites, strong-motion HVSR are found to be shifted with respect to weak-motion and ambient-noise ones, indicating non-linear behaviour of the corresponding soil materials. An attempt is made to explain the obtained results using available geotechnical information, and 1D modelling.

### INFLUENCE OF VARIABILITY OF GEOTECHNICAL DATA ON THE SEISMIC GROUND RESPONSE – ID 1149

*F. Lopez-Caballero, Ecole Centrale Paris, France*
*P. Soulloumiac, Ecole Centrale Paris, France*

In the earthquake engineering practice the quantification of local site effects on the ground motion at the soil surface is of particular importance for earthquake resistant design. It is well known that the ground response depends of both the material properties of soil profile and the rock input motion. Furthermore the uncertainty in the estimation of input motion, the soil mechanics properties (e.g. Vs, density, Shear modulus, etc) vary within the profile and their evaluation in the laboratory exhibits some degree of uncertainty.

Traditionally, in the practice the variation of shear modulus and damping ratio with distortion, known as shear modulus degradation and damping ratio (i.e. G-g and D-g) curves, has been known to be a significant feature of the soil behaviour submitted to cyclic loading resulting in the extensively used equivalent-linear approach.

Many authors propose G-g and D-g mean curves to characterize the behaviour of different kinds of soils. Thus, a probabilistic analysis can be performed in order to illustrate the effect when using uncertainty G-g and D-g curves on the ground seismic response of a soil profile. In this work, a probabilistic hyperbolic model is proposed in order to take into account easily a considerable variation about the mean curve of shear modulus degradation and damping ratio in different kinds of soils. This model is introduced in a program based on the equivalent linear approach and assuming vertically propagating seismic waves. The uncertainties associated with the shear modulus degradation and damping ratio on the ground motion (i.e. PGA, frequency content) are quantified using three reliability methods, Taylor series, point estimate method and montecarlo simulations.

### NON-LINEAR SEM NUMERICAL ANALYSES APPLIED TO SLOPE STABILITY UNDER DYNAMIC EXCITATION – ID 1100

*M. Stupazzini, Ludwig-Maximilians-Universitaet, Germany*
*C. Zambelli, Politecnico di Milano, Italy*
*C. Di Prisco, Politecnico di Milano, Italy*
*G. Festa, Institut de Physique du Globe, France*

Due to the lack of numerical codes capable at simulating the complexity of the propagation process, from the source up to the local site, engineers tend often to simplify both the seismic input and the constitutive material modelling. In order to overcame this kind of problems, we implemented into a dynamic Spectral Element code a non-local viscoplastic constitutive model characterised by a non-associated flow rule and by an anisotropic strain hardening. Hence, the numerical code is both capable (i) to excite the area under study with a realistic finite source and (ii) to take into account the non-linear response of soils triggered by strong ground motion. In this paper we apply the technique to a realistic study case of slope stability under dynamic excitation and we compare the results with those obtained by employing other simpler numerical techniques. A clear outlook on the benefits and drawbacks of the methods is here provided.

### STRONG MOTION RECORDS AT THE TOMAKOMAI LIQUEFACTION ARRAY DURING THE 2003 TOKACHI-OKI EARTHQUAKE – ID 471

*S. Nishimoto, Civil Eng. Research Institute for Cold Region, Japan*
*S. Miwa, R&D Center, Tobishima Corporation, Japan*
*T. Ikeda, R&D Center, Tobishima Corporation, Japan*

Liquefaction array observation has been conducted in soft ground at Tomakomai City, Hokkaido, Japan, to evaluate the effectiveness of the liquefaction countermeasures. The ground of the observation sites in the Yufutsu basin consists of loose secondary volcanic ash and sand deposits, whose N value is 10 or less at a G.L. (ground level) of -15 to -20 m. Liquefaction occurred in this area during the Tokachi-Oki Earthquake in 1968 and Urakawa-Oki earthquake in 1982. Liquefaction array observation has therefore been conducted at two sites in this area to measure the ground acceleration and pore water pressure during the ground motions simultaneously. The two observation sites are the section with a dominant sand layer and the section with a dominant volcanic ash layer in the ground. During the 2003 Tokachi-Oki Earthquake,

a clear built-up of excess pore water pressure and peak ground acceleration exceeding 120 cm/s2 were observed. The acceleration response spectra with periods of less than 3 seconds were amplified in the surface ground with 35 m depth. Shear modulus decreased because the strong ground motion caused large deformation of surface ground and increasing of excess pore water pressure. Also, the primary natural frequency of the ground was about 80% of that recorded for small ground motions in the past. These two pieces of evidence confirmed that the amplification characteristics of the surface ground are non-linear. Strong motion with relatively long periods of about 5 to 8 seconds was also observed. From the degree of wave dispersion, particle motion, and delay in predominant time of the wave group, it was assumed that the observed motion was surface waves excited in the deep, extensive sediment deposits of the Yufutsu basin. Long-period ground motion can be predominated in any plain with deep sedimentary layers.

### ANALYSIS OF A CLAY DEPOSIT SEISMIC RESPONSE IN EASTERN CANADA – ID 1315

*M. E. Rahhal, Saint Joseph University, Lebanon*
*G. Lefebvre, Sherbrooke University, Canada*

The 1985 Mexico City earthquake was a remarkably large event, where it was proved that damage from earthquakes is closely related to ground conditions. The presence of clay deposits in Eastern Canada, make the area predisposed to a behavior similar to the one observed in Mexico City. The 1988 Saguenay earthquake that hit this Eastern Canadian area caused a variety of geotechnical damages. The aim of the research is to understand how earthquake motions at bedrock level can be drastically modified in frequency contents and amplitude as the seismic waves are transmitted through clay deposits.

Many clay deposits in the Saint Lawrence valley and other Quebec areas were examined. These mainly soft and sensitive clay deposits have a thickness of more than 20 m. The clay is generally normally consolidated or slightly over consolidated. A typical undrained shear strength Cu profile is considered. Dynamic properties variations with the shear strain are obtained from analysis of resonant column results. As for the earthquake motions characteristics, the acceleration recorded at Saint Pascal during the 1988 Saguenay earthquake is considered. One dimensional ground response analysis of layered sites was carried out.

Acceleration amplifications by the clay deposits were measured both in time and frequency domains. In the time domain, accelerations measured at the soil surface were as much as seven times higher than those measured on the neighboring rock, when rock accelerations were less than 3%g. This amplification was reduced to a factor of 3 when rock accelerations were greater than 10%g. The effect of the deposit thickness as well as the relation between the ground response spectrum period and the deposit fundamental period were largely investigated. At large deformations the influence of the plasticity index as well as the void ratio became more evident when analyzing the response spectrum.

### APPLICATION OF HEURISTIC SEARCH METHODS TO INVERSION OF SPECTRAL RATIO OF EARTHQUAKE RECORDS IN VERTICAL ARRAY – ID 464

*H. Yamanaka, Tokyo Institute of Technology, Japan*

Analysis of spectral ratio obtained from earthquake data in a vertical array is one of the well-known techniques to estimate physical parameters of shallow soils. Usually soil parameters are derived so as to find a good fitting between observed and calculated spectral ratios with the least squared inversion methods. Although the least squared methods are well-established, we have some troubles in practical application of the least squares inversions, such as numerical instability and dependence of solution to initial model. In this study, we apply heuristic search methods to inversion of spectral ratio from earthquake records in a vertical array to estimate S-wave velocity and damping factors of shallow soils. The search methods that are investigated in this study are genetic algorithms, simulated annealing and their hybrid method. First we estimated convergence speed and stability of solutions in the three algorithms using synthetic spectral ratio. The genetic algorithms and simulated annealing shows similar convergence speed to near-optimal solution. However, simulated annealing can find models that are much closed to true model. The hybrid method can find similar models with faster convergence speed. These results clearly indicate high performance of heuristic search algorithms in soil parameter identification from vertical array records. Then, we applied them to actual spectral ratios from vertical array records observed during main shock and aftershocks of the 2003 Tokachi-oki earthquake (M8.0) in Hokkaido, Japan. We found differences in S-wave velocity and damping in the inverted models from the aftershocks and main shock indicating nonlinear effects of soils.

## CS5-IV: Site Response and Site Effects

Thursday 13:30 - 15:00 – Room 1

### SITE AMPLIFICATION FACTORS AND THEIR CHARACTERIZATION: PROPOSAL OF VS_10M – ID 772

*H. Kawase, Kyushu University, Japan*
*H. Matsuo, Hitachi System & Service, Japan*
*Y. Nejime, Kyushu University, Japan*

Adequate evaluation of the strong motion characteristics is indispensable for quantitative strong motion prediction. For empirical prediction we need relationships between averaged S-wave velocity of ground and site amplification factors. We utilize separated site factors obtained from strong motion data of K-NET, KiK-net, and the JMA Shindo-kei network in Japan. The separation was performed by using conventional spectral inversion method with a hard rock site with an S-wave velocity of 3.45 km/s as a reference. Based on the spectral site factors and one-dimensional theoretical S-wave amplification analysis, we invert the best S-wave velocity structures for 1,352 sites in Japan. We obtained very good results for 590 sites among them. At the same time we separate site factors for strength indexes such as Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV). We then try to find the relationships between spectral site factors and site factors of these strength indexes and averaged S-wave velocity of ground. After thorough studies we conclude that the averaged S-wave velocity over only 10m (Vs_10m) from the surface is sufficient to predict site factors quantitatively for PGA and PGV, as well as JMA seismic intensity scale. As for the averaged site amplification characteristics for site categories based on Vs_10m we found that the peak amplification factor reaches 10 times at 2.5 Hz for sites with Vs_10m $<$ 200m/s, while it would be around 2 for sites with Vs_10m $>$ 800m/s up to 15 Hz. The standard deviation would be around 2.0 (0.3 in log10) irrespective of the categories. If we calculate relative amplification of the sites with Vs_10m $<$ 200m/s with respect to the engineering bedrock (i.e., sites with Vs_10m $>$ 400m/s), then peak amplification will be 3.5 at 3.0Hz, which roughly corresponds to 60% of the whole amplification.

### COMPARISON BETWEEN VS30 AND OTHER ESTIMATES OF SITE AMPLIFICATION IN ITALY – ID 270

*M. Mucciarelli, University of Basilicata, Italy*

During 5 microzonation projects in Italy, we had access to 34 estimates of Vs30 obtained with down-hole or cross-hole measurements, plus 14 velocity profiles obtained with surface techniques. In all the sites we performed HVSR measurements to verify the presence of a resonant frequency and in 22 sites we installed seismic instrumentation to record earthquakes and estimate site amplification. It is important to note that we did not pre-selected the sites, but just followed the requests of two Regional governments (Marche and Basilicata) to study a set of localities that were chosen for reasons other than geo-morphological ones (previous earthquakes, pilot studies, design of new infrastructures). The comparison between site seismic amplification and Vs30 showed that this last parameter is not a good proxy of observed site effects.

The reason why in Italy Vs30 does not provide satisfactory estimates is linked to peculiar geological settings that are widespread in our country. The main problems encountered are underestimations by Vs30 at sites with velocity inversions and overestimations on deep basins. Vs30 seems to work fine only if a site has a strictly monotonic velocity profile increasing with depth and a strong impedance contrast in the first dozen meters. Further data will be available thanks to an ongoing national project funded by the Civil Defence Department that is focusing on Vs30 estimates in the presence of velocity inversions, fractured rock masses, landslides and karst areas.

### AMPLIFICATION AND ATTENUATION OF SEISMIC GROUND MOTION DURING THE MW7.0 MYIAGI-OKI EARTHQUAKE – ID 393

*D. Assimaki, Georgia Institute of Technology, United States*

Current state-of-practice site response methodologies primarily rely on geotechnical and geophysical investigation for the necessary impedance information, whereas attenuation, a mechanism of energy dissipation and redistribution, is typically approximated by means of empirical correlations. The scarcity of geotechnical information and error propagation of measurement techniques, usually result in predictions of surface ground motion that poorly compare with low amplitude observations, a discrepancy even further aggravated for strong ground motion. In this paper, we illustrate that seismic observations of site response can be complementary to geophysical and geotechnical investigation procedures, providing information on the in-situ material behavior under true seismic loading. In particular, a hybrid optimization scheme, comprising a genetic algorithm in series with a local least-square fit operator, is used for the inversion of weak and strong motion downhole array data, recorded by the Japanese Strong Motion Network Kik-Net. Aftershock inversion is first employed for the estimation of low-strain dynamic soil properties at five stations. Successively, inversion of the mainshock empirical site response is employed to extract the equivalent linear dynamic soil properties at the same locations. Finally, the observed amplification and inverted attenuation factors are categorized according to the currently established Vs30 site classification system. Results illustrate drawbacks of contemporary seismic code provisions in strong motion site response assessment, and highlight the necessity for re-evaluation of the site classification system based on observations.

### DETERMINATION OF VS-MODELS FOR THE BASEL REGION: ARRAY MEASUREMENTS, SASW AND S-WAVE REFLECTION – ID 291

*H. B. Havenith, ETH - SED, Switzerland*
*D. Fäh, ETH - SED, Switzerland*
*U. Polom, GGA, Germany*
*A. Roulle, BRGM, France*

In the frame of a new seismic microzonation of the Basel region, an extensive geophysical survey has been carried out in order to better constrain the S-wave velocities and geometrical properties of the surface layers. The survey included array measurements, SASW, and S-wave reflection seismics. Here, we will focus on the application of the array technique applied by the SED. The array method consists of recording ambient noise with a series of seismological stations. The signals are processed through FK-analysis in order to determine the dispersion of surface waves contained in the noise. The inversion of the dispersion curve provides a 1D Vs-model for the investigated site. This array method is particularly well adapted to determine S-wave velocities of sites with a thick sediment cover – such as sedimentary basins. Basel is located in the upper Rhine Graben filled with several hundreds of meters of sediments. In this region about 30 measurements with stations in different array configurations have been carried out to determine the Vs properties of various geological layers down to a depth of 100-250 m. At eight sites, SASW and S-wave reflection seismics were carried out by the BRGM and GGA, respectively. For these sites, the outputs of the array measurements were compared with the results of the two other investigations to outline similarities and differences. Thereby, array measurements and SASW revealed to be quite complementary. The combination of the dispersion curves produced by both techniques allowed us to determine precisely the properties of the shallow layers (contribution of SASW) and get valuable information about the Vs of the deeper layers (contribution of array measurements). The outputs of all measurements (including also H/V data) were implemented in a new geophysical model used as input for earthquake ground motion simulations.

### VULNERABILITY MAPPING FROM 800KM: INCLUDING GMES TERRAFIRMA PROJECT RESULTS FOR ISTANBUL – ID 1638

*C. Browitt, Edinburgh University, UK*
*M. Aktar, Kandilli Observatory and Earthquake Research Inst., Turkey*

Since 2003, radar satellite data for many cities from Dublin to Haifa and Moscow to Sofia have been used to map their ground movements, exploiting the 13-year archive of raw information now held by the European Space Agency. Under the project title of GMES Terrafirma, partners have been established across the European-Mediterranean region to extend scientific and practical applications in the service of citizens, Governments, industry and commerce, and their results are now emerging to provide examples within a spectrum of ground movements that can be detected using Persistent Scatterrer radar Interferometry (PSI). They include landslides, subsidence, compressible soils, mines and engineered excavations and, through these observations, vulnerability to earthquake shaking can be recognised.

Radar satellites, in orbits 800km above the Earth, have been collecting data through the European Space Agency (ESA) since 1992, and have been providing information on ground movements at the centimetre scale. Just 5 years ago, a new processing technique (PSI), developed by TRE in Italy, allowed a ten-fold improvement in capability so that movements of less than 1 millimetre per year can now be measured. Applied to the earthquake – threatened city of Istanbul, this leading edge technology heralds the prospect of vulnerability mapping over large areas, at low cost, with improved risk assessment and the focusing of resources for remedial action. Ground vulnerability is the parameter in the risk equation which has been least understood and is least quantifiable.

For Istanbul, the PSI data illustrates, in general terms, why significant damage in the western part of the city, furthest from the 1999 Izmit earthquake, was more significant that that in the eastern parts. Small-scale subsidence observed from space over the whole of the city, identifies that relative vulnerability and picks out reclaimed land and buried river channels.

## CS5-V: Site Response and Site Effects

Thursday 15:30 - 17:00 – Room 1

### EARTHQUAKE DISPLACEMENT SPECTRA IN ASSESSING THE PHYSICAL VULNERABILITY OF BUILDINGS - A CASE STUDY – ID 1103

*M. Bostenaru Dan, ROSE School, Italy*

The physical vulnerability of buildings is well assessed by displacement spectra. Therefore their shapes need a further study, which was initiated in this paper. Considered were the displacement spectra for the intermediate depth far-field earthquake in Vrancea (1977) and the near field shallow depth one in Erzincan (1992). Surprisingly, both were characterised by long-period pulses with small duration, which explains and was reflected in the destructiveness of the motions on flexible structures. The models of motions in forward and/or backward pulses or as sinusoides previously done were reviewed, as well as studies on the dependence of magnitude and site conditions of the shape of the horizontal displacement response. The analytical expressions for the displacement spectra

derived by Faccioli (2004) were calibrated for the earthquakes considered, using the parameters suggested, the velocity pulse half duration and the peak ground consideration, and proved to be consistent in the computations, despite the difference in the seismic source models. Although the source mechanism must have been different, the effects on structures of the two earthquakes were similar, due to astonishingly similar (by a dampling factor of 5%) displacement spectra shapes. Similar were the deep and alluvial soil conditions. For the comparison reinforced concrete frame structures were considered. Most of destruction was documented in literature for buildings with more than 4 storeys, which is consistent with the deformation based verification carried out. Since displacement spectra prove to be a good vulnerability assessment mean, it can only be emphasised that microzonation studies taking that as a base, as they have been recently put forward, have a high potential.

Reference: E. Faccioli, R. Paolucci and J. Rey, Displacement spectra for long periods, Earthquake Spectra 20(2) (2004) 347-376.

## GROUND MOTION PARAMETERS FOR VULNERABILITY ASSESSMENT – ID 1790

*A. Ansal, BU-KOERI, Turkey*
*G. Tonuk, BU-KOERI, Turkey*

Microzonation studies were carried out for five major municipalities located in different parts of the Marmara Region. Depending on the availability of geological and geotechnical data the investigated areas were divided into total of 821 cells by a grid system of 500m×500m or 250m×250m cells. For each cell representative boreholes were assigned for estimating the effects of site conditions. Site response analyses were conducted for each cell utilizing an equivalent linear model (Shake91) using three previously recorded hazard compatible in terms of magnitude, fault type and fault distance; acceleration time histories as outcrop motion scaled with respect peak ground accelerations determined from probabilistic and deterministic seismic hazard analysis for each cell.

Site specific ground motion data were produced to be used for microzonation with respect to ground shaking intensity, liquefaction susceptibility, and landslide hazard in addition to the assessment of the vulnerability of the building stock. The simpler option was to calculate directly NEHRP design spectrum using average shear wave velocity. The second option is to determine the NEHRP design spectrum based on the average of the three acceleration response spectrum calculated by site response analyses for each cell utilizing a fitting algorithm giving the best outer envelop in terms of NEHRP design spectrum. The results obtained are compared in terms of short period (0.2 sec) and long period (1.0 sec) spectral accelerations obtained for NEHRP. It was observed that the spectral accelerations determined by fitting procedure for NEHRP vary in much broader range and in some cases, it was observed that the simplified procedures would yield values on the unconservative side compared to those determined by the site response analyses.

## ACCELEROMETRIC DATA JOINT INVERSION AND SITE EFFECTS CHARACTERIZATION – ID 1768

*S. Drouet, OMP, France*
*S. Chevrot, OMP, France*
*F. Cotton, LGIT, France*
*A. Souriau, OMP, France*
*P. Gueguen, LGIT, France*

Spectral inversion of large sets of ground motion records have long been used either to compute source properties (magnitude, corner frequency) or to compute site effects. In this study we propose an inversion of Swave Fourier spectra in the frequency band 0.5/15 Hz to obtain simultaneously seismic moments, corner frequencies, anelastic and geometric attenuation parameters, as well as site effects. We use an iterative GaussNewton method to solve this nonlinear problem. Datasets composed of accelerometric records from different (seismically active) areas in France (Alps, Pyrenees, Rhine Grabben). The earthquakes have local magnitudes ranging between 3.0 and 5.5, and are recorded at distances between 15 and 200 km. We assume that the farfield displacement spectrum is the product of source, propagation and site effects. A Brune'stype source is used and attenuation is decomposed in a frequency dependent term of the form Q=Qofalpha (anelastic attenuation) and a nonfrequency dependent term (geometric attenuation). The inversions give moment magnitudes which have the same correlation with local magnitudes in the three regions, and are 0.5 to 1 unit lower than local magnitudes, a results also observed on Swiss data (Braunmiller, 2005). The anelastic attenuation shows a frequency dependence of the form Q of 0.4, with Qo ranging from 200 to 500 depending on the region. The geometric attenuation is approximately equal to the theoretical one for bodywaves (1/R). Finally, robust site effects are computed which are consistent with other independent studies.

## PSHA IN NORTHERN ITALY ACCOUNTING FOR NON-LINEAR SOIL BEHAVIOUR AND EPISTEMIC UNCERTAINTY – ID 1464

*F. Pelli, Geodeco S.p.A., Italy*
*M. Mangini, Geodeco S.p.A., Italy*
*P. Bazzurro, Geodeco S.p.A., Italy*
*C. Eva, Università di Genova, Italy*
*D. Spallarossa, Università di Genova, Italy*
*S. Barani, Università di Genova, Italy*

The paper describes the analyses carried out to assess the ground surface seismic hazard for an area in Northwest Italy. Alluvial deposits characterize the investigated area, and at some locations boreholes, down-hole shear velocity tests and microtremor records were available. The nonlinear effects of the soil layers on the intensity of the ground motion at the surface were captured by a site-specific, frequency-dependent amplification function, AF(f), where f is a generic oscillator frequency. In this study we utilized a simplified but accurate approach for probabilistic site amplification assessment in non-linear soil deposits. At each location the AF(f) values were obtained via regression from those of "pilot" soil columns that were previously analyzed. Thousands of nonlinear dynamic analyses were performed using a modified version of the non-linear computer program SUMDES and a suite of real rock ground motions. At each location in the area under consideration the regressed median AF(f) and related uncertainty were then coupled via convolution with the site-specific bedrock hazard to obtain the desired surface hazard for the site (e.g., Bazzurro and Cornell, 2004a and b). Where the results of specific geotechnical investigations were available, AF(f) was also predicted, for comparison purposes, by a suite of ground motion records driven through a site-specific finite element model of the soil deposit with uncertain properties. Since the amplification functions as provided by the simplified approach depend also on the elastic fundamental frequency of the soil column, the analysis of microtremor records provided useful information. Some analyses included also the epistemic uncertainty in the input seismicity parameters, in the soil characteristics and in the amplification functions. Maps with PGA and spectral accelerations for a given mean return period and uniform hazard response spectra at a few locations will be presented.

## MACHINE LEARNING FOR GROUND-MOTION RELATIONS – ID 1438

*S. Garcia, Institute of Engineering, UNAM, Mexico*
*M. Romo, Institute of Engineering, UNAM, Mexico*

Earthquake ground motions are affected by source, path, and local site response effects. These effects are typically combined for implementation in seismic hazard analyses, where attenuation relations are used to define the occurrence of an earthquake with a particular magnitude at a specific distance from the site. Because of the uncertainties inherent in the variables describing the source (included magnitude, epicentral location, depth and source dimensions), the difficulty to define categories for characterizing the site term (e.g., rock and soil) and our lack of knowledge about wave propagation process from source to site, it is very common that the predictions from attenuation regression analyses are inaccurate.

This article investigates how machine learning ML methods might

enhance current ground-motion relations in that they contribute to more adaptive solutions. ML processes data representing past experiences and tries to either develop an appropriate response to future data, or describe in some meaningful way the data seen. A heterogeneous catalog (thousands of ground-motion records for events of M $\geq$ 5 at distances up to several hundred Kilometers from Cascadia region, Japan, Mexico and South America) containing events from many regions and including various tectonic and soil-type environments is used to develop ML global ground-motion relations for interface and in-slab earthquakes, using a regression tree approach.

The final ML scheme can be used to predict accurately the damaging levels of motion for future earthquakes (in terms of response spectra ordinates) and to describe the dependencies between the input quantities that govern the physical process. The learning tool seems to be a very promising alternative to describe the earthquake phenomena despite of the limited observations, judgment, partial knowledge of geotechnical conditions, and ambiguous reasoning employed to infer the behavior of the poorly-defined universe.

### SITE EFFECTS ON DISPLACEMENT RESPONSE SPECTRA BASED ON DIGITAL STRONG MOTION RECORDS – ID 566

*R. Paolucci, Dept. Structural Eng., Politecnico di Milano, Italy*
*E. Faccioli, Dept. Structural Eng., Politecnico di Milano, Italy*
*R. Figini, Dept. Structural Eng., Politecnico di Milano, Italy*
*D. Finazzi, Dept. Structural Eng., Politecnico di Milano, Italy*

It has already been widely recognized that the standard way to calculate design displacement spectral ordinates by simply dividing the acceleration spectrum by the square of the natural frequency may lead to unacceptable errors at long periods, especially in view of the increasing role of displacement based approaches in current seismic design. Based on the increasing availability of good quality digital records from strong earthquakes throughout the world, a considerable research effort has been done in the recent years to calibrate improved displacement spectral shapes, and to check their dependence on the more relevant parameters for seismic hazard analyses and for seismic design. The calibration of site amplification factors suitable for seismic design at long periods is the object of this paper. For this purpose, a relevant set of digital accelerograms from the Japanese Kyoshin network (K-Net) have been selected, in order to cover with a sufficient number of records the various site classes. After a careful examination of the influence of different baseline correction procedures on the long-period spectral ordinates, and of different criteria for site class definition based on the available soil profiles, average site amplification factors are derived, by taking the ratio of the average response spectra at long periods for the different site classes. The effect of magnitude and distance on such site factors is also discussed.

## CS6-I: Early Warning, Shaking and Loss Scenarios

Thursday 13:30 - 15:00 – Room 3

### AN UPDATE ON USGS SHAKEMAP DEVELOPMENTS, USES, AND RELATED TOOLS – ID 1078

*D. Wald, U.S. Geological Survey, United States*
*B. Worden, U.S. Geological Survey, United States*
*V. Quitoriano, U.S. Geological Survey, United States*
*K. W. Lin, U.S. Geological Survey, United States*

We discuss ongoing development and enhancements of the U.S. Advanced National Seismic System (ANSS) ShakeMap system developed under the auspices of U.S. Geological Survey. ShakeMap is a system for automatically generating maps of ground motion and intensity in the minutes following an earthquake. The rapid availability of these maps is of particular value to emergency response organizations, utilities, insurance companies, government decision-makers, the media, and the general public. We describe ongoing advances in the use and delivery of ShakeMap with particular emphasis on our recent efforts to facilitate automated use of ShakeMap for decision making, beyond simply "looking" at ShakeMap. To this end, we describe ShakeCast, short for ShakeMap Broadcast, a fully automated system for delivering specific ANSS ShakeMap products to critical users and triggering established post-earthquake response protocols. We also introduce new products like RSS feeds for automatically receiving ShakeMap files, XML and KML formats for Google Earth and other software, and other new tools. The latest ShakeMap release includes an uncertainty measure, quantified as a function of location on the map, which is critical for evaluating the range of possible losses, and allows users to gauge the appropriate level of confidence when using rapidly produced ShakeMaps as part of their post-earthquake critical decision-making process. Finally, we describe the use of predictive ShakeMaps for earthquake Scenarios as well as for the rapid evaluation of significant earthquakes globally in our new system referred to as PAGER, for Prompt Assessment of Global Earthquakes for Response (see Earle and Wald, this meeting). These global ShakeMaps are constrained by rapidly gathered intensity data via the Internet and by automated moment tensor or finite fault and rapid aftershock analyses for portraying fault rupture dimensions. All USGS ShakeMap and related products can be found at http://earthquake.usgs.gov/shakemap.

### THE CONFIDENCE OF EARTHQUAKE DAMAGE SCENARIOS; EXAMPLES FROM THE CAPACITY SPECTRUM METHOD – ID 1416

*C. Lindholm, NORSAR, Norway*
*S. Molina, Dpto. Ciencias de la Tierra y del Medio Ambiente, Spain*

Earthquake loss modelling is about to become an important tool in mitigation planning. Loss modelling is based on a parameterized mathematical representation of the damage problem, and while the mathematical representation models will certainly improve, the question of sensitivity to uncertain parameterization becomes vital. In this work we will investigate the importance of the uncertainties of the input parameters in a seismic risk computation. The capacity spectrum method (CSM) is used, and the examples identify some parameters that contribute significantly to the results, and thereby to the confidence levels. The results demonstrate that loss scenarios may easily vary by as much as a factor of 2 due to simple parameter variations. Of particular importance for the uncertainty is the craftsmanship quality of the structure. The results represent a warning against naive acceptance of damage scenarios and strongly support the development of computational methods in which parameter uncertainty is carried through the computations facilitating confidence bounds for the damage scenarios.

### IMPLEMENTATION OF RISK-UE APPROACH FOR CREATION OF EARTHQUAKE RISK SCENARIOS FOR THE CITY OF BITOLA, MACEDONIA – ID 1253

*Z. Milutinovic, IZIIS, Macedonia*
*G. Trendafiloski, IZIIS, Macedonia*
*T. Olumceva, IZIIS, Macedonia*

RISK-UE Scenario analyses approach is used to define the safety and reliability margins of the City of Bitola as well as to provide elements for short and long-term mitigation strategy, prevention measures and an adequate action plan to be implemented in the city (WP9). The required quantifications are obtained through implementation of different RISK-UE workpackages (WP1-WP7). Two seismic risk scenarios are created for the City of Bitola: 1) Macroseismic (L1); and, 2) Spectral displacement scenario (L2). The L1 scenario is considered as a minimum requirement for the city. The seismic demand, in terms of EMS-98 intensity, is estimated deterministically based on historical earthquakes with significant impact on the city. LM1 fragility models are used to quantify the expected damage potential. The L2 scenario is considered as the worst-case scenario. The seismic demand, in terms of spectral displacement, is estimated using PSHA (475 years return period). LM2 fragility models are used to quantify

the expected damage potential. For both scenarios the greatest contribution to the level of seismic risk in the city is estimated by the expected damages and economic losses from future events. The largest damaging potential is expected in the traditional building types with more then 60% contribution to the overall economic losses. The earthquake casualty potential in the City of Bitola is estimated as relatively low, amounted to 0.6-0.8‰ of the total affected population. The seismic performance of the essential lifeline systems (water and power supply) is estimated as favorable and serious adverse effects are not expected to the overall urban system behavior and response.

### RAPID ESTIMATION OF SEISMIC INTENSITY DISTRIBUTION ON THE BASIS OF INVERSION FOR HUGE EARTHQUAKE – ID 914

*M. Kuse, Gifu University, Japan*
*M. Sugito, Gifu University, Japan*
*N. Nojima, Gifu University, Japan*
*Y. Enomoto, Gifu University, Japan*

At the Nankai trough that is off-shore of the middle of the Honshu and Shikoku Island in Japan, the huge earthquakes occurred repeatedly. Because the huge earthquake along this region has not occurred for many years, the danger of its occurrence has been pointed out in recent years. Confronting these earthquake disasters, we need the seismic intensity distribution as the minimum required information for the effective disaster-prevention measures. If we can take in the seismic intensity distribution based on detailed parameters of source process right after an earthquake, the distribution will be useful information for rescue and restoration. This study presents the technique for the rapid estimation of detailed seismic intensity distribution in extensive area based on the source process that is calculated by the inversion technique developed by Kuse et al. (2004). In this study, the technique is applied to the huge scenario earthquake named Tokai Earthquake that occurs along the Nankai Trough. The strong motions generated assuming the recurrence of the huge scenario earthquake are used in the inversion. These assumed records are generated by strong motion prediction model EMPR (Earthquake Motion Prediction model on Rock surface) developed by Sugito et al. (2000). The acceleration envelopes calculated from the acceleration time histories are used in the analysis, and the asperity pattern of strong motion energy on the fault was estimated by the inversion technique. Next, for the rapid estimation of seismic intensity distribution, the interpolation technique developed by Kuse et al. (2000) is used. For shortening the required time for data processing, in this interpolation technique, the points that should be simulated are selected in accordance with the shortest fault distance. As a result, the acceleration envelops and seismic intensity distribution based on the estimated asperity pattern were consistent with those result based on the assumed asperity pattern.

## CS6-II: Early Warning, Shaking and Loss Scenarios

Thursday 15:30 - 17:00 – Room 3

### LOSS SCENARIOS AND WARNING METHODOLOGIES: VALIDATION WITH ITALIAN EARTHQUAKES – ID 362

*F. Bramerini, Servizio Sismico Nazionale, Italy*
*A. Lucantoni, Servizio Sismico Nazionale, Italy*
*F. Sabetta, Servizio Sismico Nazionale, Italy*

The procedure adopted by Italian Civil Protection for the earthquake loss scenarios has been significantly improved with new methodologies and data bases. In particular different loss estimation models are considered, taking into account empirical fragility curves and damage probability matrices as a function of Peak Ground Acceleration (PGA), Arias Intensity (IA), Effective Peak Acceleration (EPA), and MCS Intensity (MCSI). The influence of the earthquake focal depth is also modelled together with a first raw evaluation of the local amplification effect based on the geotechnical classification of the site. The new building inventory data, coming from the last population census (ISTAT 2001), allow to switch from the former consideration of single dwellings to the individual buildings: the vulnerability inventory of the residential buildings uses the EMS scale for a correct estimation of the ERD (Earthquake Resistant Design), improving substantially the vulnerability assessment. The calibration of the buildings distribution has been made using the post-earthquake survey databases of the last 30 years. Moreover the time of the event is also considered for the estimation of the casualties. A specific warning methodology has been developed, allowing to assign a different alert level based on the expected losses rather than simply on the earthquake magnitude. The loss scenarios and the warning methodology have been validated through the comparison with the losses and casualties data of several Italian earthquakes of the last 30 years, including the last 2002 Molise and Puglia earthquake.

### CAPABILITIES OF BAYESIAN PROBABILISTIC NETWORKS APPROACH FOR EARTHQUAKE RISK MANAGEMENT – ID 1458

*Y. Y. Bayraktarli, Inst. Structural Engineering, ETH Zurich, Switzerland*
*U. Yazgan, Inst. Structural Engineering, ETH Zurich, Switzerland*
*A. Dazio, Inst. Structural Engineering, ETH Zurich, Switzerland*
*M. Faber, Inst. Structural Engineering, ETH Zurich, Switzerland*

The present paper considers large-scale risk based decision making in regard to management of earthquake hazards. First an outline is given on existing methodologies on management of earthquake hazards in terms of capabilities and shortcomings. Thereafter a recently developed generic risk assessment framework is introduced which takes basis in a system representation through exposures, direct and indirect consequences as well as vulnerability and robustness. The framework is fully generic in the sense that the characteristics of the system are formulated in terms of risk indicators which may be specified in accordance with the available information concerning a given system. Furthermore, the framework is fully Bayesian such that probabilistic models and consequently also the risk assessments can be updated based on new information of relevance for the decision making. This in turns allows for considering the different decision situations, before, during and after an earthquake takes place, subject to the available information in the different situations. The basic properties of Bayesian Probabilistic Networks (BPN) are shortly introduced. Taking basis in previously developed BPN based risk assessment tools for vulnerability analysis of structures and soil, the presented framework is then illustrated through an example where a risk based decision analysis on possible retrofitting or rebuilding of building structures in a larger part of a city is performed for the two different situations - before and after an earthquake.

### "SCENARIO SISMICO": A TOOL FOR SEISMIC RISK ANALYSES AND REAL TIME DAMAGE SCENARIOS IMPLEMENTATION – ID 912

*A. Balbi, Provincia di Genova, Italy*
*A. Galasco, University of Genoa, Italy*
*S. Giovinazzi, University of Genoa, Italy*
*S. Lagomarsino, University of Genoa, Italy*
*S. Parodi, University of Genoa, Italy*

"Scenario Sismico" is a GIS tool thought, designed and implemented by the authors for the simulation and the representation of seismic risk analyses and real time damage scenarios in Liguria Region for use by regional and local Civil Protection departments and government officials. Hazard, vulnerability, exposure and damage maps are directly evaluated on the digital cartography provided by Liguria Region, where a common analysis unit is identified, and displayed by using the ALOV Map/TMJava application. Hazard scenarios are directly evaluated by the tool once the position, the magnitude and, possibly, the hypocentral

depth is provided. EMS-98 macroseimic intensity is employed to describe the resulting shaking. Intensity increments are applied to account for particular morphological conditions assessed from the Digital Elevation Model provided by the Liguria Region. The characterization of the exposed building-stock is obtained processing the available census data according to a GIS automatic procedure allowing updating in the case of new data availability. The seismic vulnerability assessment is therefore obtained applying a macroseimic approach properly specified for the building typologies recognized in the territory. All the meaningful information available on the building-stock and the site effects are accounted for by the vulnerability assessment procedures.

Once the earthquake scenario is set, physical damages, losses and consequences to people are automatically obtained and displayed in terms of thematic maps or data-base sheets. The results are provided in the form of possible range, as uncertainties inherent in the steps included in the proposed loss estimation tool have been considered.

This paper is addressed to the descriptions of the methodological framework at the basis of the "Scenario Sismico" tool. In addition, examples will be provided to show the efficacy of this tool in providing real time damage assessment and its usefulness in supporting the planning of technical and non-technical mitigation strategies.

### REAL TIME IDENTIFICATION OF MAJOR EARTHQUAKE DISASTERS WORLDWIDE FROM ALGERIA M6.7, 2003 TO KASHMIR – ID 613

*M. Wyss, WAPMERR, Switzerland*

The aim of real time loss estimates (number of fatalities, injured and damage) is to distinguish major disasters from minor ones, such that international help can be offered with minimal delay, yet unnecessary mobilizations of rescue teams are avoided. During the last three years, WAPMERR has issued real time alerts for potentially damaging earthquakes, world wide. All earthquake disasters large enough to warrant an international response were identified as such. No minor disasters were misidentified as in the Algerian earthquake of 2003, whereas in others, as in the Kashmir 2005 earthquake, the number of fatalities was underestimated (our initial alert spoke of "thousands of fatalities" instead of tens of thousands). Using the Kashmir experience to calibrate our earlier estimate of future losses of life in Himalayan earthquakes (Wyss, March 2005), we find that the latter should be corrected upward by multiplying by a factor of 2.4. To assist with improving the data set on building fragility in developing countries, we have collected high resolution satellite images for 700 cities in earthquake prone areas. From these we can construct 3D models of these cities, in which we can count the buildings in height classes of our choice. In addition, these images are now stored in a library, where we can access them in real time, once one of these cities is hit by an earthquake. In such a case, we intend to make these images available in real time, along with our alerts, for rescue teams and disaster managers to assist them in planning and executing rescues. Over the years, our response time has decreased from about two hours to 30 minutes. We conclude that our alert system is successful, yet our service can be improved by an order of magnitude.

### UNCERTAINTY OF PORTFOLIO LOSS ESTIMATES FOR LARGE EARTHQUAKES – ID 1117

*G. Molas, Risk Management Solutions, Inc., United States*
*R. Anderson, Risk Management Solutions, Inc., United States*
*P. Seneviratna, Risk Management Solutions, Inc., United States*
*T. Winkler, Risk Management Solutions, Inc., United States*

While it is important to estimate the expected losses for large scenario events, it is equally important to be able to quantify the uncertainty of these loss estimates. The objective of this study is to quantify the uncertainty of loss estimates for a large scenario event at several levels of geographic resolution: postal code, county, and state. The sources of uncertainty considered are from both the ground motion and the loss ratio modeling.

The 1906 San Francisco earthquake is presented as a case study. Monte Carlo simulations are applied around the median ground motion estimates based on attenuation equations. The simulation accounts for the inter- and intra-event components of the variance of the predicted ground motion. Spatial correlation principles are implemented in the simulation to generate a correlated random field to realistically represent the ground motion distribution between sites within a certain separation distance. Each simulation generates a ground motion footprint over the area of interest at 1 kilometer grids, from which the losses are calculated.

The distribution of the structure types located within the grid cell is assumed to be deterministic. However, the loss ratios within the grid cell are determined with uncertainty estimates. The losses are then aggregated to produce a probabilistic loss estimate for one ground motion simulation. The probabilistic loss estimates for all simulations are then combined to characterize the probability distribution of the total event loss. The loss estimates are also calculated at postal code and county levels. The geographic variation in loss uncertainties is evaluated by comparing the coefficients of variation (CV) across the study area.

The results of this study can be used to gain a better perspective of the range of possible loss values for a scenario event, which is very useful for disaster planners, risk managers, etc.

### REAL-TIME GROUND MOTION FROM THE NEW STRONG MOTION SEISMIC NETWORK IN BRITISH COLUMBIA, CANADA – ID 689

*A. Rosenberger, Geological Survey of Canada, Canada*
*G. Rogers, Geological Survey of Canada, Canada*

Canada's chief vulnerability to earthquakes is concentrated in a few urban regions. The Pacific coast of the province of British Columbia is subject to the hazard posed by the Cascadia subduction zone with the associated earthquake scenarios of shallow crustal events, deeper subcrustal events and magnitude 9 megathrust earthquakes.

The Geological Survey of Canada operates a new real-time ground motion reporting network of accelerographs in British Columbia. As of January 2006, one-hundred instruments have been deployed, most concentrated in and around the urban centres of Vancouver and Victoria.

The instruments combine several functions, serving as continuously recording strong motion accelerographs, and at the same time, as sensors which automatically detect events and report real-time ground motion parameters such as peak ground acceleration (PGA), velocity (PGV), and spectral intensity (SI). Instruments form a network using various physical means of communications, including wired, wireless and satellite Internet links. Standard Internet protocols are employed to convey ground motion reports.

The whole network of instruments thus does not depend on the existence of a seismic data centre to analyze full waveform data, generate an alarm and subsequently dissiminate ground motion maps. Instead, ground motion parameters from an instrument are relayed directly to disaster response agencies and lifeline and critical infrastructure operators. A prototype client system, which depicts peak ground motion values on a thematic map, is in operation with the Ministry of Transportation in British Columbia.

The reliability of alarms from this network as well as the quality of the generated shake maps depend primarily on station density. Since the instruments are inexpesive to own, deploy, and operate, dense arrays have become a realistic proposition.

## CS6-III: Early Warning, Shaking and Loss Scenarios

Friday 10:45 - 12:15 – Room 3

### DEMONSTRATIVE EARLY WARNING SYSTEM IN THE EASTERN PYRENEES – ID 651

*X. Goula, Institut Cartografic de Catalunya, Spain*
*B. Colas, Bureau de Recherches Geologiques et Minieres, France*
*J. Jara, RSE S.A., Spain*

*N. Romeu, RSE S.A., Spain*
*P. Dominique, Bureau de Recherches Geologiques et Minieres, France*
*T. Susagna, Institut Cartografic de Catalunya, Spain*
*J. Irizarry, Institut Cartografic de Catalunya, Spain*
*O. Sedan, Bureau de Recherches Geologiques et Minieres, France*
*M. Montserrat, CRECIT, Andorra*
*A. Roca, Institut Cartografic de Catalunya, Spain*

The existing seismic information systems at the present time in Europe are limited in the amount of provided useful information. With the purpose of improve this situation a demonstrative automatic seismic information system (ISARD project) has been developed on the Eastern Pyrenees (some Provinces in Spain, a French Department and Andorra). A real time system based on a VSAT seismic network has been developed first in Catalonia and now it is operational in an extended region, with 3 new accelerometric stations in France, 1 in Andorra and a total of 18 seismic stations for the seismic network . This project is financially supported by FEDER, by the French Environment Ministry and the Catalan Public Works Department. The system can generate automatically few minutes after the earthquake to authorized people (Civil Defence crisis managers) an informative note with the estimation of the possible damages based on three different soft modules: i) Seismic Automatic Determination (SAD) of the hypocentral parameters of a local earthquake recorded in quasi real time. The system is founded on Earthworm tools, developed in the USGS and adapted to the local conditions of the seismic VSAT network; ii) Automatization of the report delivering with the estimated focal parameters, via Fax, SMS or Internet (TeleAvis). It is possible to define, thorough filters, the conditions required to the focal parameters performed by SAD to be sent, as the quality of the determination, or the threshold value for the magnitude; iii) Automatic damage scenarios generation corresponding to the eventual damages caused by an earthquake and automatic delivery of tables and maps (SAED). The scenarios are defined following vulnerability assessment methodologies applied to the scale of district's area, using GIS techniques. This automatic seismic information system can contribute to enhance the management of the crisis and share country's first-aid organizations

## EARTHQUAKE EARLY WARNING SYSTEM AT A LOCAL GOVERNMENT AND A PRIVATE COMPANY IN JAPAN – ID 741

*H. Negishi, Nation. Res. Inst. for Earth Sci. and Disas. Prev., Japan*
*S. Yamamoto, Nation. Res. Inst. for Earth Sci. and Disas. Prev., Japan*

We have developed the Real-time Earthquake Information System, which provides earthquake information just few seconds after P-wave arrival at the nearest station from a hypocenter (Horiuchi et al., BSSA, 2005). This system determines hypocenter and magnitude immediately by using telemetry seismographs network operated by National Research Institute for Earth Science and Disaster Prevention (NIED). Thus we get early warning for big ground motion before it begins in an area a little far from hypocenter. Now we are conducting the actual proof experiment in collaboration with a local government and a private company, in order to verify the validity and practicality about the broadcasting and application of this information. The earthquake alarm information is automatically sent from NIED to the Fujisawa City Office, Kanagawa, Japan, for large earthquake occurrences. Data processing PCs at the office estimates seismic intensity and S-wave arrival time and display them. The PC has a function to control an eight-channel electric relay automatically according to the information, so we can control patrol lights, some instruments, etc. We started the system in July 2002, and now the 14 public halls, two municipal schools and a city hospital have this system. Tokio Marine Nichido Risk Consulting Co., Ltd., risk consulting subsidiary of one of the major casualty insurance companies in Japan, introduced this system in June 2003. The earthquake alarm information is mainly used for the employee's safety. Data processing PCs transmit intensity and S wave arrival time to the monitor unit (a display, speakers and a four-colored patrol light) and employee's cellular phones. We are also using it for the business of the company. The earthquake information synchronizes with "Payment insurance calculation system", and estimates the payment insurance and calls members for the damage assessment automatically.

## URBAN SYSTEM UNDER EARTHQUAKE THREAT. APPLICATION TO THE AZORES – ID 616

*C. S. Oliveira, Instituto Superior Técnico, Portugal*
*J. M. Proenca, Instituto Superior Técnico, Portugal*
*M. A. Ferreira, Instituto Superior Técnico, Portugal*
*F. Mota De Sá, Fuzzy, Lda, Portugal*
*J. C. Nunes, Universidade dos Açores, Portugal*
*M. L. Sousa, National Laboratory for Civil Engineering, Portugal*

Assessing and managing earthquake risks are topics being developed in recent years. In the Azores much advancement was recently accomplished in the area of the earthquake sources and wave propagation, even though there are no complete models to explain the seismo-tectonics of the archipelago. The present project follows a previous one developed in the period 1997-2001, which contributed to the seismic hazard and risk assessment in the Central Group of the Azores Archipelago. The present project aims at the development of a general methodology for creating earthquake-risk scenarios that takes into consideration the distinctive features of Azores Island. Particular attention will be given to the response of the urban centres behaving as an entire system, considering the economic impact and population reaction (Hollistic view). In order to achieve this goal some detailed methodologies will be developed to analyse the vulnerability of existing housing in large towns of Terceira, Faial and Pico, applying the EMS-98 macroseismic scale concepts and mechanical techniques to model seismic response of buildings constructions. The influence of the soil layers (geological and geomorphologic effects), slip in mapped faults and evaluation of the possible landslides and liquefaction will be taken into account. An automatic seismic scenario loss estimate methodology integrated on a Geographic Information System (GIS), which comprises modules evaluating bedrock seismic input, local soil effects, vulnerability and fragility analysis and human losses analysis will be applied to Azores Archipelago. This permits the end-user to carry out a complete seismic risk assessment and to produce seismic risk scenarios and seismic risk maps at three geographical scales: "freguesia (city council)", "subsecção estatística (city block)" and individual building. The application of system analysis to urban centres in Azores (USuET) will be an important tool to help emergency planning, online impact evaluation, and for urban and land-user planners.

## SELECTION OF NATURAL AND SYNTHETIC SEISMIC INPUT FOR EARTHQUAKE SCENARIOS – ID 1898

*A. Masi, DiSGG, University of Basilicata, Italy*
*M. Mucciarelli, DiSGG, University of Basilicata, Italy*
*M. Vona, DiSGG, University of Basilicata, Italy*

Many studies on the seismic vulnerability assessment of building structures confirm the strong role of the seismic input characteristics. In this work, after a short description of the main ground motion parameters (strong motion, energy, duration), non linear dynamic analyses on some RC frame structures are performed (Masi, 2003). The examined structures are present in the European building stock and are representative of building types designed only to vertical loads. Further, by recognizing the major role of masonry infills in the seismic behaviour of buildings without earthquake resistant design, building without infills, regularly infilled, and with pilotis are examined. Artificial, simulated and recorded time histories are used in the simulations. Artificial accelerograms are generated using the SIMQKE code. Simulated accelerograms are obtained from a computer program named BELFAGOR derived from an older code (Mucciarelli et al., 1997). Both artificial and simulated accelerograms are spectrum-compatible with the EC8 elastic response spectra for

B ground type. Real accelerograms recorded during past seismic events are used, mainly drawn from the European strong-motion databank. The seismic response and the relevant damage levels of the examined structures are evaluated and compared as a function of the main ground motion parameters. When using artificial accelerograms generated unrealistic damage levels are computed, thus they appear inadequate for earthquake scenarios. They are too onerous when compared to real accelerograms, assuming equal PGA values, because of their damage potential and frequency content. Results closer to the behaviour shown by RC buildings in past earthquakes are obtained by applying real accelerograms. However, using them the results show a very high scatter. Intermediate results are obtained using simulated time histories generated by the BELFAGOR code, able to mimic real accelerograms for similar magnitude, distance and site conditions and, at the same time, converge in frequency domain to a reference response spectrum.

### STATION DENSITY AND ITS ROLE IN THE EVOLUTION OF EARTHQUAKE EARLY WARNING ESTIMATES – ID 1665

*G. Cua, ETH Hoenggerberg, Switzerland*
*T. Heaton, California Institute of Technology, United States*
*S. Wiemer, ETH Hoenggerberg, Switzerland*

The Virtual Seismologist (VS) method is a Bayesian approach to earthquake early warning that facilitates the use of diverse types of information in real-time earthquake source characterization. In the early stages of the earthquake rupture process when observed ground motions are scarce, the VS estimates are highly influenced by relevant prior information such as previously observed seismicity, network topology, and known fault locations. Station density in the source region plays an important role in how the source estimates and their associated uncertainties evolve with time. Source estimates and uncertainties, and not the source estimates alone, play a pivotal role in the decision-making process of subscribers attempting to use early warning information to initiate damage-mitigating actions before the onset of destructive ground motions.

To illustrate the effects of station density on the evolution of VS estimates, we will compare how the VS method would have performed during the 2004 M6.0 Parkfield earthquake using 1) low density real-time stations transmitting data to the California Integrated Seismic Network and 2) the high density California Geological Survey and US Geological Survey strong motion array, had they been transmitting data in real-time. We attempt to characterize “sufficient” station density as a function of user requirements in terms of available warning time and uncertainty on source estimates. We attempt to address 1) whether the potential benefits of early warning information justify the costs of additional station deployments given the current costs of instrumentation, and 2) whether the cost-benefit ratio becomes more attractive with different instrumentation strategies (for instance, a high density of real-time strong motion sensors, as opposed to joint broadband and strong motion installations). Such cost-benefit analyses may help determine which types of applications, and which source-region/target warning area geometries are best suited to early warning.

## CS7-I: Strategies in Earthquake Mitigation

Friday 10:45 - 12:15 – Room 1

### EARTHQUAKE PREPAREDNESS IN ROMANIA AND KNOWLEDGE DISSEMINATION IN A JICA PROJECT ON SEISMIC RISK REDUCTION – ID 348

*E. S. Georgescu, NCSRR and NATIONAL INSTITUTE FOR BUILDING RESEARCH, Romania*
*T. Kaminosono, JICA-NCSRR, Romania*
*K. Miyara, JICA-NCSRR, Romania*
*R. Ghica, NCSRR, Romania*
*C. P. Stamatiade, MTCT, Romania*
*G. Ionescu, MTCT, Romania*

The seismicity of Romania, is dominated by large Vrancea intermediate depth earthquakes, with high intensities over 50% of the territory and recent disasters in 1940 and 1977. Since the recurrence is at some decades, it is difficult to keep alive the public awareness. The paper presents the needs and means of earthquake preparedness of citizens and school students education and training, as a long-term program of the Ministry of Transports, Construction and Tourism – MTCT, Romania. As a counterpart activity, JICA – Japan International Cooperation Agency, in cooperation with MTCT, financed a Japan-Romania Project on Seismic Risk Reduction, on 2002-2007, having the National Center for Seismic Risk Reduction – NCSRR as implementing agency, INCERC and UTCB as partners. The first and most critical issue is to increase the active involvement of apartment owners in retrofitting their high-rise buildings that represent a first class of risk and a public danger. Many of them avoid to engage in strengthening works, although they recognize the risk, although financial incentives from public funds are quite advantageous. The paper evaluate Japanese means of knowledge dissemination for convincing and training citizens for risks mitigation. However, knowledge transfer must be adapted to Romanian conditions, since earthquakes have other patterns, while structures and citizens perceptions are different. We used seminars with Japanese Experts, booklets and posters to inform citizens, as well as questionnaire surveys. For earthquake education of students, the difficulty is related to the need of permanent mass knowledge transfer through booklets and posters, curricula and periodical disaster response exercices. We describe the new set of educational materials, made in 2005-2006 by MTCT-INCERC, with collaboration of NCSRR-JICA Experts. Other issues refer to the legal framework improvements due for 2006, in order to stress-out the situations of public danger, the compulsory examination and, if necessary, strengthening of buildings.

### TRAINING PEOPLE FOR DISASTERS IN RESIDENTIAL COMPLEXES - FROM RISK TO OPPORTUNITY – ID 1376

*M. Hosseini, IIEES, Iran (Islamic Republic Of)*
*Y. Izadkhah, Humanitarian Resilience, Cranfield University, UK*

In recent years, "Community-Based Disaster Management" (CDBM), has been held to be one of the most effective means of successful disaster management in various communities. This also applies to large populated cities, composed of various small communities, where the rescue activities can be hindered due to a variety of factors, which include the disruption of urban transportation systems. In fact, issues such as delay in announcing the location of earthquake epicenter and suitable rescue routes and access paths have resulted in rescue teams being less effective in the initial crucial hours following an earthquake. This is also to some extent applicable to other disastrous events, where provision of aid by the local people at the site is considered to be one of the most efficient sources of assistance in the very first hours after the event. The process can be facilitated more effectively if it is to be applied to an area with pre-defined borders. With this in mind, it is reasonable to expect that trained residents of a residential complex (whose numbers may vary from tens to hundreds) are the first people who can assist the casualties without delay. An attempt has been made in this paper to explain issues with regard to these kinds of training programmes and their implementation in various communities- particularly the populated complexes of large cities in developing countries. The paper also discusses the roles of various groups of people including women and children, and how they can be trained to provide necessary assistance.

### THE SOCIAL CHALLENGES AGAINST EARTHQUAKE MITIGATION IN TURKEY FOCUSING ON CULTURE OF PEOPLE LIVING – ID 681

*K. Eraybar, Istanbul Technical University, Turkey*
*A. Ilki, Istanbul Technical University, Turkey*

115 Earthquakes causing death, have been experienced in Anatolia, since 1900. It is predicted that approximately 90.000 people died and 300.000 people got injured as a consequence of these earthquakes. In the latest earthquakes of Kocaeli and Duzce in 1999, effecting Marmara region, almost 20.000 people lost their lives.

Eastern Marmara region, which was severely effected by the 1999 earthquakes, had become an intensively industrialized area before these earthquakes, as a result of wrong regional development strategies. The area became very attractive to the people migrating from rural areas since it offered wide job opportunities and relatively higher level of salaries. Because of large numbers of migrants, official construction sector got insufficient in covering the demand of housing needs, and many buildings had been constructed with low quality workmanship, with no or very low level of engineering input and low quality of construction materials. It should be highlighted that the inspection system did not work either, both due to technical and ethical problems.

On the other hand, both quiting the rural areas and being peasant, the new inhabitants of cities had so many confusions and difficulties in metropols. This problem created the social reason of having this unhealthy stock of constructions. Not being able to entegrate into the city, they created their own culture –as may be called "squatter culture"- with the identity of neither peasant nor city dwellers. These people were not only more vulnerable to disasters but also effected all layers of the society by their living and thinking attitudes.

In this study, it is examined if 1999 Marmara earthquakes are turning points from the social aspect to eliminate the unhealhty constructions complained about. Some social, economic and legal mitigation suggestions are offered to the countries experiencing the same period as Marmara region.

### COMBINED EFFECTS OF FIBRE MORTARS AND REINFORCED POLYMERS ON THE SEISMIC CAPACITY OF MASONRY STRUCTURES – ID 784

*E. Juhasova, Institute of Construction and Architecture SAS, Slovakia (Slovak Republic)*
*R. Sofronie, University of Bucharest, Romania*
*M. Hurak, HurakLtd, Slovakia (Slovak Republic)*

The masonry structures belong to the most vulnerable structures which have recorded heavy damage or total collapse due to earthquakes. Many actual structures and large models were investigated by authors in the framework of national and international research projects. Investigation of large scale masonry models tested on shaking tables in different European laboratories gave enough data for the theoretical and numerical analysis of the seismic response mechanism and for building the basis of practical rules for the design of new and for upgrading of existing structures. The paper will present the main milestones of research, synthesis of obtained results and the estimate of contribution of fibre mortars and reinforced polymers to the total seismic resistance of masonry structures. Examples of numerical analysis and experiments will be represented by results obtained for asymmetrical masonry structures of one and two storeys constructed from solid masonry units both with the use of fibre mortars and reinforced polymers. Discussion on the strategy for the mitigation of seismic vulnerability of these frequently built structures is carried on in relation to different seismic input scenarios.

### SEISMIC REINFORCEMENT OF ADOBE HOUSES USING EXTERNAL POLYMER MESH – ID 632

*M. Blondet, Catholic University of Peru, Peru*
*D. Torrealva, Catholic University of Peru, Peru*
*J. Vargas, Catholic University of Peru, Peru*
*J. Velasquez, Catholic University of Peru, Peru*
*N. Tarque, Catholic University of Peru, Peru*

Earthquakes occurring in developing countries demonstrate again and again that adobe houses are highly vulnerable and that millions of people who live in these houses are at great risk. This underscores the urgency to find simple and economic solutions to reinforce adobe houses.

This paper summarizes a research project developed to explore the use of plastic meshes as reinforcement for adobe structures. Four full-scale adobe house modules were tested on the shaking table of the Catholic University of Peru. The first module was unreinforced and represented a typical adobe dwelling. Its behavior under strong shaking was quite poor, with brittle failure of the walls. The second module was overreinforced by completely wrapping all walls with a polymer mesh. During the dynamic tests the module moved practically as a rigid body, with little damage on the adobe walls and a sliding failure of the walls on their concrete foundation. The third module had a more sparse reinforcement consisting of bands of a lighter polymer mesh, placed at selected locations. Its seismic behavior was quite good, because although the walls were damaged, the reinforcement bands were able to hold the pieces together and collapse was therefore averted. The fourth module was reinforced with a plastic mesh used as protection during road works, which is far cheaper than the polymer mesh used for the previous two modules.

The seismic simulation test results show that it is possible to use plastic mesh as a convenient seismic reinforcement of adobe houses. The next steps will be to optimize the reinforcement design and to develop guidelines for the retrofit of existing houses and the design and construction of new seismic resistant adobe houses.

### GEOTECHNICAL RISK AND THE URBAN EXPANSION OF THE COASTAL METROPOLE OF GREATER BEIRUT – ID 12

*J. Harb, Notre Dame University, Lebanon*

The paper investigates several sectors in the Greater Beirut Area where in case of a seismic event a considerable geotechnical risk is present. The most significant one is the risk of liquefaction that exists at several sites, sometimes exceeding 80 % probability for a return period of 50 years. Moreover urban expansion on these geotechnically risky areas has neither been refrained nor controlled by legislative building regulations. A graphical representations of the results are key tools for urban planners, engineers and insurance industry, all concerned by urban risk and natural hazards.

## CS7-II: Strategies in Earthquake Mitigation

Friday 13:30 - 15:00 – Room 1

### JOINT RESEARCH PROJECT ON DISASTER MITIGATION BY APPLYING THE INFORMATION SHARING PLATFORM – ID 479

*S. Takeyasu, Kawasaki Laboratory, NIED, Japan*
*G. Yozo, Kawasaki Laboratory, NIED, Japan*

It is well known that the lack in information sharing led to an enlargement of earthquake damages in the Hyogo-ken Nambu earthquake of 1995. In the Niigata-ken Chuetsu (the central Niigata prefecture) earthquake of October 23, 2004 and the Niigata and Fukushima heavy rainfall of October 2004, however, lessons learned in the past events of disaster were not necessarily reflected in terms of information sharing. For the purpose of mitigating damages due to disasters, a research on disaster mitigation using crisis-adaptive information sharing technology was commenced in July, 2004, as a three year joint project between government office and agency, national research institutes, universities, a NPO and a private company. National Research Institute for Earth Science and Disaster Prevention (NIED) is in charge of project management as the representative organization. Major research items conducted are as follows: (1) Development of the disaster information sharing platform (2) Analysis and regulation on rules for disaster information sharing (3) Development of spatial data preparation methods (4) Development of systems to collect

disaster information by local inhabitants and to transmit disaster information to local inhabitants (5) Research on disaster mitigating countermeasures making efficient use of shared information The development of communication protocol and database system for the platform has been completed. The research on information items and spatial data transmitted through the platform has been proceeded. Systems for information collection and transmission, simulators and information sharing systems for local governments, lifeline corporations have been developed. Then, proof tests are scheduled to be conducted this year, in which the developed systems and tools are applied experimentally to actual local governments to prove their effectiveness. This paper introduces the results of the project still in progress for the last two years.

### SHOULD WE WORRY ABOUT THE POTENTIAL SEISMIC HAZARD IN A REGION OF MODERATE SEISMICITY? – ID 1532

*J. S. Kuang, Hong Kong University of Science and Technology, Hong Kong*

During the past three decades, most of research efforts in earthquake engineering were concentrated on the earthquake disaster mitigation for regions of high seismicity. It was not until the earthquake in Newcastle, Australia, in 1991, which was a medium earthquake but caused about 2.5 billion US dollars of damage, that attention to the potential seismic hazard in moderate seismicity regions was revived. This earthquake reveals that although the seismic intensity of an earthquake is not high, it may cause a significant loss of life and economy.

In regions of low to moderate seismicity, engineers normally do not include seismic considerations in buildings design. This is true for many territories, such as Hong Kong, the UK and many other parts of Europe and Asia. A structure which is designed and detailed based only on gravity and other incidental horizontal loads would have to rely on its inherent ductility to acceptably respond to unexpected seismic excitations.

The primary objective of this paper is to present the need for earthquake resistance consideration in building designs in moderate seismicity regions, based on the case studies of Hong Kong. Experimental studies of large-scale specimens on the seismic behaviour and inherent ductility of non-seismically designed reinforced concrete structures, as practised in low probability of seismic occurrence regions, have been presented, which include columns, shear walls, beam-column joints, frames and wall-frame structures.

It is deducted that the earthquake risk of building structures in a region of moderate seismicity is not nil. The experimental results have revealed that the inherent ductility of non-seismically designed and detailed RC structures may not sufficiently satisfy the ductility demand for the requirements in moderate seismicity regions. Modifications in detailing techniques for non-seismic design should be made in order for improving the seismic performance and enhancing the ductility of non-seismically designed RC structures.

### AN ECONOMIC-ENGINEERING APPROACH FOR UPGRADING THE SEISMIC PERFORMANCE OF EXISTING BUILDINGS – ID 1074

*D. Segal, NBRI-Technion, Israel*
*S. Schwarz, NBRI-Technion, Israel*
*D. Yankelevsky, NBRI-Technion, Israel*
*E. Leibowitz, NBRI-Technion, Israel*
*I. Nasseiri, NBRI-Technion, Israel*

This paper presents a methodology to determine the optimal level of seismic upgrading of existing buildings, based on economic-engineering criteria. The optimal upgrading level is determined as the one that involves the minimum life cycle cost to the user and to the society. The life cycle cost in this case is composed from: - The present investment that represent the cost of: upgrading design, materials and labor works needed for the upgrade and the cost of building dysfunction during the upgrading works. - The present value of expected costs of seismic damage (cost of damage to building, cost of fatalities, cost of injuries, cost of lost contents and cost of dysfunction of the building during the repair period) The methodology is comprised of the following stages: - Seismic design of different upgrade levels and corresponding cost estimates - Nonlinear analysis of the original building and its upgraded versions to different earthquake magnitudes - Damage estimation to the structure and finish works. - Economical assessment of human life-loss and injuries for each upgraded level, under a given seismic loads. - Determine of the optimal upgrade level of an existing building. It is based on the cost of upgrade and the expected cost of the estimated damages. The methodology can be applied to evaluate the optimal level of seismic design and for the evaluation of an optimal level of seismic upgrading of a group of different types of existing buildings to achieve a maximum benefit from a limited budget. The paper will present the proposed approach and demonstrate its capabilities through a worked out example.

### RATIONAL SEISMIC DESIGN AND REDESIGN OF HEALTH CARE FACILITIES – ID 316

*V. Davidovici, Dynamic Concept, France*

Hospitals and other health facilities are focal points for any community and, after a disaster, play a vital role in attending to the injured. There is a widely held expectation that such facilities are prepared to deal with any crisis.

When designing hospital buildings and equipment for seismic regions, seismic hazard must be taken into account in the early stages, thus achieving a structurally sound system at an acceptable cost.

This report starts with a summary of structural, non-structural and functional damage to medical care facilities worldwide between 1952 and 2004.

Drawing on numerous references and analyses of the effects of earthquakes on health facilities, the report contains brief presentations of recent conceptual design and redesign against seismic hazard. The main structural factors are described in detail.

The report also investigates the interaction between hospital buildings and equipment during seismic activity.

Hospitals must remain fully operational in the event of an earthquake. The report describes the combination of seismic risk with expected performance (Building configuration, Structural performance, Structural details, Non-structural components and Equipment) so that medical care facilities can continue to operate effectively, both during and after an earthquake.

### A GLOBAL EARTHQUAKE VULNERABILITY ESTIMATION SYSTEM (GEVES): AN APPROACH TO INSURANCE RISK – ID 1491

*R. Spence, Department of Architecture, Cambridge University, UK*
*L. Leone, Cambridge Architectural Research Ltd, UK*
*H. Castella, PartnerRe, Switzerland*
*G. Andrea, PartnerRe, Switzerland*
*S. Jenny, PartnerRe, Switzerland*

Earthquake loss estimation is increasingly important for the insurance and reinsurance industry, in order to estimate adequate insurance and reinsurance premiums that account for the potentially large losses resulting from earthquakes. Current methods tend either to rely on the limited historical damage and loss data or on the numerical simulation of the response of individual buildings to the ground shaking produced by earthquakes. In many countries, however, the lack of detailed information on buildings and ground shaking renders the second approach difficult to implement in any realistic way. At the end neither approach is satisfactory for many insurers.

During 2005, Parterre, in association with CAR Ltd, set out to develop a new generation of loss models to fit with their own existing earthquake occurrence models. The aim was to provide inventory and economic loss data for earthquake occurrence in 32 different countries and regions, based on local understanding of the factors affecting losses. The resulting product known as GEVES (Global Earthquake Vulnerability Estimation System) was required to have the following features: · Transparency · Based on the best available worldwide expertise · Derived from and tested against real observed losses, including the most recent · Explicitly dealing with uncertainty

at each step · Simple to apply for a range of clients' needs

A key assumption was that macroseismic intensity rather than spectral displacement would be the basis of loss estimation. The paper describes the model with emphasis on its structure and the justification for the assumptions made. The paper will also discuss validation of the model against calculated approaches and observed losses, and the treatment of uncertainty within the model.

### PROPOSAL OF A NEW RISK FINANCE METHOD FOR BUSINESS CONTINUITY – ID 1461

*S. Nishikawa, Cabinet Office Disaster Management, Japan*
*S. Fukushima, Tokyo Electric Power Services Co. Ltd, Japan*
*H. Yashiro, The Tokio Marine & NIchido Risk Consulting Co., Japan*

To minimize economic damage by sudden disasters such as earthquakes, securing immediate funding for business recovery is indispensable. In Japan, we have witnessed cases where enterprises had to abandon its operations due to shortage of immediate funds for business recovery after earthquakes. The Japanese Government recently issued a set of business continuity & disaster preparedness guidelines where it calls for businesses to plan for quick resumption of operations. There are some existing methods for risk financing, for example, earthquake insurance and ART. However, there is still room for better risk financing methods to be developed. In this paper, the pros and cons of existing risk financing methods are examined. A new method is proposed, combining features of earthquake insurance and parametric triggered ART with focus on minimizing basis risk by providing possibilities for refund by recipient when the immediate damage is limited. A model portfolio of 10 building assets in Tokyo Metropolitan area was applied in analyzing the performance of this method. Through the application, the following findings were obtained; this method allows sufficient risk transfer as provided by earthquake insurance and also enables immediate funding since it does not need waiting for damage assessment, compared to existing ART methods this method enables lowering the cost by risk takers, hence, this method is attractive for both the recipient and the risk takers and has good possibility to be a new tool for risk financing.

## CS8: Secondary Earthquake Hazards: Tsunami, Landslide, Rock Fall, Liquefaction

Friday 13:30 - 15:00 – Room 3

### EARTHQUAKE LOSSES DUE TO GROUND-FAILURE (LANDSLIDES, LIQUEFACTION) – ID 1262

*J. Bommer, Imperial College London, UK*
*J. Bird, Arup Geotechnics, UK*

Earthquake loss estimation models aim to estimate the likely impact of future seismic events on the built environment. A key question to be addressed when designing an earthquake loss model is whether it is sufficient to focus purely on the damage caused by ground shaking, or whether collateral hazards should also be considered. This paper begins with a review of 50 damaging earthquakes in recent years to identify the proportion of the overall damage – both to buildings and to infrastructure – caused by ground failure rather than directly by strong motion. These observations provide an overview of the situations in which the impact of these secondary earthquake hazards can be sufficiently important to warrant their inclusion in a loss model, given that this invariably requires substantial additional effort in data collection.

The paper then reviews the way that losses due to landslides and liquefaction are modelled in HAZUS, which is one of the only openly documented earthquake loss estimation methodologies to explicitly incorporate these secondary seismic hazards. The critical review suggests that these are amongst the less-developed elements of the HAZUS loss modelling approach, requiring large amounts of field data that then feed into rather crude estimates of the impact. The damage due to liquefaction estimated using HAZUS are compared with field observations from the 1999 Kocaeli earthquake in Adapazari.

The paper considers the feasibility for developing improved approaches, in which the inherently very large uncertainties in estimating the nature and extent of these ground-failure hazards – which is much larger than the already considerable uncertainty in estimating ground-shaking hazard – become a primary consideration. A new approach for estimating losses due to liquefaction – combining displacement-based mechanical elements with empirical components – is presented. The issues related to simultaneously estimating losses due to ground shaking and due to ground failure are also discussed.

### TSUNAMI HAZARD AND RISK ASSESSMENT ALONG THE WESTERN COAST OF THAILAND – ID 1897

*H. Bungum, NORSAR, Norway*
*C. B. Harbitz, NGI, Norway*
*F. Løvholt, NGI, Norway*
*C. Lindholm, NORSAR, Norway*
*S. Glimsdal, NGI, Norway*
*F. Nadim, NGI, Norway*

The present study has been aimed at developing recommendations for how to deal with the future tsunami risk in Thailand in both short and long term perspectives. The 2004 tsunami wave caused an inundation (flooding) level ranging along the coast from 5 to 10-12 m above mean sea level, and these levels and their spatial distributions have been confirmed by detailed numerical simulations. The source model used was based on available seismological inversions and subsequently adjusted based on a fine-tuning against the inundation observations. The study finds that another megathrust earthquake affecting the coastline of Thailand is not likely to occur again for several hundred years, in part based on the assumption that a barrier near the Simeulue Islands will prohibit significant rupture across it, and in part based on the decreasing subduction rates north of the Banda Aceh region. It is also concluded that the largest credible earthquake to be prepared for along the part of the Sunda-Andaman arc that could affect Thailand, is in the short to medium term (say within the next 50-100 years) an earthquake of magnitude 8.5, which is expected to occur with more spatio-temporal irregularly than the megathrust events. Expected inundation levels here will be up to 1.5-2.0 m along the west coast of Thailand. For an M 8.5 earthquake and tsunami scenario, the potential consequences to human life and property will therefore be modest. However, in a longer time perspective (say more than 50-100 years) the potentials for earthquakes of similar magnitude and consequences as the 2004 event will become gradually larger and eventually posing an unacceptable societal risk. The study has therefore recommended taking some mitigation measures immediately, including land-use planning, escape routes, building code adjustments, etc.

### GENERATION, PROPAGATION AND IMPACT OF SCENARIO TSUNAMIS IN THE CORINTH GULF (GREECE) – ID 1951

*S. Tinti, Università di Bologna, Dipartimento di Fisica, Italy*
*A. Armigliato, Università di Bologna, Dipartimento di Fisica, Italy*
*S. Gallazzi, Università di Bologna, Dipartimento di Fisica, Italy*
*A. Manucci, Università di Bologna, Dipartimento di Fisica, Italy*
*G. Pagnoni, Università di Bologna, Dipartimento di Fisica, Italy*
*R. Tonini, Università di Bologna, Dipartimento di Fisica, Italy*
*F. Zaniboni, Università di Bologna, Dipartimento di Fisica, Italy*

The Gulf of Corinth is characterised by active extensive tectonics and by very relevant seismicity, with historically recorded highest magnitudes in the order of 6.8-7. The seismicity, together with the steep coastal topography/bathymetry and the high sedimentation rates, are responsible for the frequent triggering of submarine mass movements. Both earthquakes and landslides contribute to the relevant tsunami hazard in the region. In

the framework of the EU project "3HAZ-Corinth", we study the generation of tsunamis in the Corinth Gulf by both earthquakes and landslides. We take into account not only sources that have been proposed as possible responsible for historical tsunamis, but also (and mainly) sources that are not necessarily associated with historical events but are believed to be potentially tsunamigenic based on different kinds of observations (geological, geomorphologic, geotechnical). For each studied case, we simulate the propagation of the ensuing tsunami in the Gulf, trying to highlight its main features, such as the different typical periods of the waves generated by earthquakes and landslides, the time evolution of the tsunami field and the geographic distribution of the predicted maximum water heights along the basin coasts. As regards the modelling techniques, the initial conditions for earthquake-generated tsunamis is taken to be identical to the vertical co-seismic deformation of the seafloor, computed through the classical linear elastic half-space approach. The dynamics of the landslides is modelled by means of an original Lagrangian numerical model, developed both in 1-D and in 2-D, in which the sliding body is split into a set of constant-volume contiguous blocks, and the equation of motion is solved in correspondence with the centre of mass of each block. Finally, the propagation of the tsunami waves is simulated through a numerical finite-element code solving the hydrodynamics equations in the shallow-water approximation.

### GEOLOGICAL EVIDENCE OF SEISMICALLY-INDUCED SECONDARY EFFECTS IN EASTERN SICILY (ITALY) – ID 2005

*C. Pirrotta, Dipartimento di Scienze Geologiche, Italy*
*P. Guarnieri, Dipartimento di Scienze Geologiche, Italy*
*M. S. Barbano, Dipartimento di Scienze Geologiche, Italy*
*F. Gerardi, Dipartimento di Scienze Geologiche, Italy*
*A. Smedile, Dipartimento di Scienze Geologiche, Italy*
*P. M. De Martini, Ingv, Sezione Sismologia e Tettonofisica, Italy*
*D. Pantosti, Ingv, Sezione Sismologia e Tettonofisica, Italy*

Eastern Sicily is a high seismicity area where some of the most disastrous earthquakes of the Italian history, such as the 1169 and the 1693 events (south-eastern Sicily) and the 28 December 1908 Messina Strait earthquake (north-eastern Sicily), occurred. These large earthquakes induced numerous secondary geological effects, which, as reported by historical sources, often caused damage to towns, even more relevant than the seismic shock itself. A multi-disciplinary study has been undertaken to find geological evidence of these effects, especially near inhabited places where the seismic hazard may increase. This study started from the sites described in the historical reports with the main goal of recognizing and dating the secondary seismic effects produced by historical and paleo-earthquakes. The well-known 1908 earthquake induced various secondary effects described by witnesses: a tsunami wave along coastal areas, several fractures rupturing the surface, numerous landslides, liquefactions and sand boils. However, only recently some of these effects have been recognized in the field. Among them, two landslides, near the Faro Superiore village, and a set of active faults, that may have participated in the distribution of the 1908 coseismic deformation at the surface. Liquefaction is one of the most common secondary features produced by earthquake shaking. Historical accounts frequently report liquefaction along the coast and in alluvial valleys. Probable evidence of liquefaction was found at several sites. In particular, at a site near Mascali, boudinage, convolutions and vented clasts are observed in soft sediments, at different levels in the stratigraphy, below the pedogenic layer, in a 3-4 meters deep ditch. Sedimentological analysis and radiocarbon dating are in progress in order to link these liquefaction features to one or more of the large historical earthquakes of the eastern Sicily and/or possibly to paleoseismic events.

### FINITE STRAIN MESHFREE ANALYSIS OF POROSITY EVOLUTION FOR EARTHQUAKE-TRIGGERED LANDSLIDES – ID 602

*S. Bernardie, brgm, France*
*E. Foerster, brgm, France*
*H. Modaressi, brgm, France*

Mechanisms involved in earthquake-triggered landslides may be various. A possible mechanism is related to the increase of pore water pressure, due to the water migration during the shaking, which may lead locally to the creation of a water film, especially at the interface between layers with contrasted physical properties (e.g. permeability), this water film then serving as a sliding surface. This phenomenon has been notably highlighted by Kokusho [Kokusho 2003] through 1D tube tests and 2D shaking table tests, which showed the creation of a water film between a liquefied sand layer and an impermeable layer. In this paper, the numerical results obtained with 1D and 2D simple non linear dynamic analyses are presented, in which we consider a loose saturated sand layer underlying either a less permeable saturated or impermeable clay layer. These simulations are performed within a meshfree framework, using a cyclic elastoplastic constitutive model [Aubry et al. 1982] under effective stress and finite strain assumptions. This latter assumption allows to measure the evolution of soil porosity and to simulate possible lateral spreading. These computations show an increase of porosity and a decrease of shear resistance in the upper part of the underlying loose sand layer, i.e. near the interface, attesting the local accumulation of water in this region. Finally, this numerical approach is applied to a real shallow earthquake-triggered landslide in Japan and results are compared with the available observations. A sensitivity analysis on some key geotechnical parameters (e.g. initial permeability and/or porosity, etc.), especially in the superficial layers, is also presented, in order to demonstrate the influence of these parameters on water film occurrence and on the prediction of final displacements.

## ES 1-I: Geotechnical Engineering
Wednesday 10:45 - 12:15 – Room 21

### SISMUR, A TOOL FOR EVALUATION OF SEISMIC RISKS ON EXISTING RETAINING WALLS – ID 372

*C. Thibault, CETE Méditerranée, France*
*D. Criado, CETE Méditerranée, France*
*G. Haïun, SETRA, France*
*P. Marchand, SETRA, France*
*D. Davi, SETRA, France*

As part of the elaboration of SISROUTE, the French tool for evaluation of the seismic risks on road sections, the vulnerability of existing structures like bridge (SISMOA), tunnels and retaining walls have to be estimated. The objective is to summarily evaluate, for different earthquakes scenarios, the risk of cut of road by failure or severe damage on the different structures of the road network.

This paper presents the qualitative method SISMUR for the evaluation of gravity retaining walls which represent the most important part of retaining walls in French seismic zones.

In the first time, the typical modes of failure, highlighted from literature review and post seismic observations, are identified and analysed facing geometrical considerations.

In the second part of the study, a state of the art of simplified methods for the seismic design of retaining walls is examined. Pseudo-static, Newmark's sliding blocks and finite elements methods have been tested in order to evaluate the movement of walls during earthquakes.

The lack of mechanical and geometrical data about soils and structures pose problems for the evaluation. From observed data, the SISMUR code estimates the threshold acceleration for sliding, overturning, bearing capacity failure of soil, and shear failure of wall. The threshold accelerations are compared to the ground accelerations calculated for different scenarios. The failure of wall's structures and the displacements induced by sliding and rotating movements are performed in terms of risk of road section's cut off for a given scenario.

Currently, the procedure SISMUR is testing on a small road section in the French area of Nice.

### DYNAMIC INTERACTION BETWEEN RETAINING WALLS AND RETAINED STRUCTURES/GEOSTRUCTURES – ID 1112

*Y. Tsompanakis, Technical University of Crete, Greece*

Retaining systems are widely used for serving various purposes (embankments, bridges, ports, etc). The seismic response of walls has been examined in the past. Nevertheless, the dynamic interaction of the retaining walls with the structures that they usually retain has not been investigated. It is evident however that during a seismic event the dynamic response of each component of this complex system (wall, soil, and structure) may affect substantially the response of the rest, and vice versa. For instance, the presence of a retaining wall will affect the ground shaking of the retained soil layers, while the existence of a structure and/or a geo-structure behind the wall may increase the dynamic earth pressures developed on the wall. In the present study, using numerical two-dimensional simulations, the influence of the wall flexibility on the free-field ground shaking behind the wall is investigated. Emphasis is given on the impact of the wall's presence on the amplification of the base acceleration on the retained soil layer, an amplification generally ignored by the seismic design codes. In the sequence, a structure founded on the retained soil is included in the numerical models, as a single-degree-of-system (SDOF) in order to examine how the location and/or the fundamental eigenperiod of the SDOF affect the earth pressures induced on the retaining wall. In addition, the parametric study investigates at what extend the presence of the wall may affect the inertia forces imposed on the structure. Finally, the case of the dynamic interaction between the retained soil, the retaining wall and a supported a geo-structure, for example a highway or any other type of embankment, is investigated. Numerical results provide a clear indication of the direct interaction between a retaining wall and its retained structures and/or geo-structures.

### A REPLACEMENT TO THE MONONOBE-OKABE EQUATIONS FOR SEISMIC EARTH PRESSURES – ID 1115

*G. Mylonakis, University of Patras, Greece*
*K. Papantonopoulos, University of Patras, Greece*
*P. Kloukinas, University of Patras, Greece*

A closed-form plasticity solution is presented for determining gravitational and earthquake-induced earth pressures on retaining walls. The solution is based on the theory of discontinuous stress fields and takes into account the following parameters: (1) weight and friction angle of the soil material, (2) wall inclination, (3) backfill inclination, (4) wall roughness, (5) surcharge at soil surface, (6) horizontal and vertical seismic acceleration. Both active and passive conditions are considered by means of different inclinations of the principal stress planes in the backfill. Results are presented in the form of dimensionless graphs and charts that elucidate the salient features of the problem. Comparisons with established solutions, such as those of Sokolovskii and Chen show satisfactory agreement (maximum error for active pressures about 5%). It is shown that the pseudo-dynamic seismic problem does not differ fundamentally from the gravitational one, as the former can be derived from the latter by means of a similarity transformation based on a rotation of the reference axes. A generalized Rankine condition involving a uniform stress field in the backfill is demonstrated as a special case. Compared to the Mononobe-Okabe equations, the proposed solution is simpler, more accurate (especially for passive pressures) and safe, as it overestimates active pressures and underestimates the passive. In addition, it can predict the pressure distribution on the wall and, accordingly, the point of application of soil thrust.

### NUMERICAL STUDY OF SOIL-PILE GROUP INTERACTION IN SANDS – ID 1333

*H. Tahghighi, Tokyo University, Japan*
*K. Konagai, Tokyo University, Japan*

A new perspective for the soil-pile group interaction analysis has recently been provided by the authors in a way that soil parameters were obtained through a classical continuum mechanics theory. Elasto-plastic soil element is expressed as a Winkler hypothesis model using a uniaxial material object and zero-length element. With the present approach, obtained results show fairly well correlations with rigorous 3D simulations and measured experimental data. Therefore the model may be conveniently incorporated as a tool in the practical design of pile foundations.

### PILED STRUCTURES STILL COLLAPSE IN LIQUEFIABLE SOILS! - THE MISSING CONSIDERATIONS IN PILE DESIGN – ID 1444

*S. Bhattacharya, University of Oxford, UK*

The collapse of pile-supported structures is still observed after strong earthquakes, despite the fact that a large factor of safety (against bending due to lateral loads and axial capacity) is employed in their design. Currently, piles in liquefiable soils are designed as beams to avoid bending failure arising from lateral loads due to inertia and/or slope movement (lateral spreading). It has been estimated the design factor of safety lies between 4 and 10. Simple tests were carried out in a centrifuge to study the failure mechanisms of piles in liquefiable soils. The research findings suggest that part of the pile in liquefiable soil needs to be treated as unsupported structural columns to avoid buckling failure. Essentially, P-delta effects should be taken into account for fully-embedded piled foundations passing through liquefiable soils. This is applicable mostly to loose to medium dense sands. The current codes for seismic pile design such as the Eurocode, Japanese code and NEHRP code, however, provide no guidance in this regard. This paper highlights the practical implications of this research.

### SEISMIC ASSESSMENT OF ANCHORED QUAY WALLS – ID 1544

*D. S. Bu, Royal Haskoning, UK*

Pseudo-static method has been widely adopted by practicing engineers to design quay wall structures under seismic conditions. In the performance-based design, however, port structures of higher performance grade should be assessed by using more sophisticated methods. PIANC recommends that time domain seismic analysis should be adopted for performance grade A or S structures. Recent advancement of computation techniques enables engineers to carry out rigorous seismic analysis without difficulties. This paper presents a seismic assessment of anchored quay wall structures. Important aspects, such as choice of input motions, element size, viscous boundary conditions, dynamic time step, damping, and hydrodynamic effect, are discussed.

## ES 1-II: Geotechnical Engineering

Wednesday 13:30 - 15:00 – Room 21

### DESIGN OF A PILED FOUNDATION PIT IN A SEISMIC AREA AND SOIL PRONE TO LIQUEFACTION – ID 82

*T. Uzunoglu, convex ZT GmbH, Austria*
*G. Anagnostides, Asprofos S.A., Greece*

The objective of the paper is to present the design of a structure in a highly seismic area under poor soil conditions susceptible to liquefaction. The structure is a cooling water intake pit and is part of a new 390 MW Power Plant designed and constructed by VA TECH Hydro on behalf of Hellenic Petroleum close to Thessaloniki in Greece. The structure has overall dimensions of 30m length, 7m width, and 8.50m depth. It is located at the shore of Thessaloniki's Gulf in a relatively flat area and has a top elevation just above sea water level. The scope of the design was

to have a robust structure with thick concrete separating walls, accommodating large pumps and auxiliary facilities. Detailed geotechnical investigations in the vicinity of the area prevails that the site consists mainly of alluvial materials which are deposited there by several rivers that are being discharged at the Gulf of Thessaloniki. The soil materials consist of loose to medium dense soft clayey and silty clayey materials, whereas layers of very stiff or very dense soil was encountered at depths of 25-30m below ground level. If this structure was designed with a conventional raft foundation then significant settlements were expected. In addition the lithological composition of subsoil formations suggest that a mass liquefaction is possible during an earthquake. To avoid these problems the pit was designed with piled foundations. Although the piled foundation provides a stiff and robust solution it raised the problem of how to design this system. The paper will present the major steps in the design of this structure, such as the seismic conditions in the area, the geotechnical investigation, the requirements of the Greek seismic regulation, and the various scenarios chosen to design the pit and its foundation.

## LATERAL EARTH PRESSURE DISTRIBUTION IN A LARGE GROUP PILE CAUSED BY FLOW OF LIQUEFIED SANDY GROUND – ID 109

*V. Sesov, Institute of Earthquake Engineering, Macedonia*
*I. Towhata, The University of Tokyo, Japan*
*R. Motamed, The University of Tokyo, Japan*

This study investigates lateral pressure distribution caused by ground flow in a large group pile. A series of shaking table test were performed on sandy ground models with embedded 6x6 and 11x11 group piles. The ground models consisted of a uniform gently sloped liquefiable soil layer and a horizontal liquefiable layer with a sloped nonliquefiable layer at the top of the model. Shaking was applied in lateral direction in respect to the direction of the ground flow. A selective number of piles were instrumented by strain gauges and bending moments were measured during the shaking. The results from the experimental investigations reveal that the liquefied sand flows through the spacing between the piles, which appears to be against the assumptions made in the existing design code. The existence of a nonliquifiable layer at the top of the ground model significantly affected the maximum bending moment of the piles. The lateral load due to horizontal flow of the liquefied slope was not uniform in the large group pile, maximum lateral pressure being observed in the front and the rear pile rows in terms of the direction of the ground flow. The total lateral force as a sum of the measured lateral forces acting on each individual pile was obtained and compared with that in the seismic design specifications. This comparison shows that the design codes reasonably well estimate the magnitude of the total lateral force, which is acting on the pile groups due to the lateral spreading of the liquefied ground.

## UPLIFTED OF BURIED MANHOLES AND PIPES DUE TO LIQUEFACTION OF REPLACED SOILS – ID 617

*S. Yasuda, Tokyo Denki University, Japan*
*H. Kiku, Kanto Gakuin University, Kazakhstan*

In 2004 a big earthquake named Niigataken-chuetsu earthquake occurred in Japan. About 1400 sewage manholes were uplifted during the earthquake. Many buried sewage pipes were also uplifted. The maximum value of the uplifted manholes was about 1.5 m. A car collided with an uplifted manhole in Nagaoka City. All uplifted manholes pipes had to be reconstructed after the earthquake. Before the restoration work, detailed soil investigations were carried out to demonstrate the mechanism of the uplift. Based on the investigation, it was clarified that the uplift occurred in mainly clayey grounds. No sand boils were observed on the clayey ground. However, boiled sands were observed just beside the uplifted manholes and on the buried pipes. During the construction of buried pipes and manholes, the ground was excavated first, placed pipes and manholes in the dug ditch, then replaced the ditch by sands. Soil investigation of the replaced soils after the earthquake revealed that replace sands were very loose and easy to liquefy. Then, it was concluded that the uplift of the manholes and pipes occurred due to the liquefaction of the replaced soils. During the restoration work, appropriate countermeasures for future earthquakes were discussed, and finally, cement mixing method was selected. This paper shows the damage of the manholes and pipes , detailed soil investigation and restoration work.

## DYNAMIC BEHAVIOR AND LIQUEFACTION RESISTANCE OF GRAVELS – ID 851

*N. Fanouraki, National Technical University of Athens, Greece*
*G. Bouckovalas, National Technical University of Athens, Greece*
*A. Valsamis, National Technical University of Athens, Greece*

Published experimental studies on the liquefaction resistance of sands and sand-silt mixtures are numerous. On the contrary, similar studies for sand-gravel mixtures are rather limited, as a result of the demand for specialized equipment imposed by the large grain size of such soil mixtures. Hence, there is lack of general consensus among experts on how to treat these soils in practice. Firstly a data base was created from 65 published liquefaction experiments performed on reconstituted sand and sand gravel soil samples. Each test is described by all physical and mechanical properties which are necessary for the following interpretation of the test results (e.g. D50, CRR, Go). The liquefaction resistance of sand-gravel mixtures was evaluated with reference to the much better known liquefaction resistance of clean sands. Two interpretation methods were used: (a) The "nominal density" method, where sand gravel mixtures are treated as clean sands with a much smaller void ratio, equal to the nominal value measured directly by standard procedures. (b) The apparent (soil skeleton) density method, where a sand-gravel mixture is seen as a gravel skeleton, with voids which are partially filled with finer sand and liquefaction resistance is related to the "apparent" void ration of the gravel skeleton. Depending upon the interpretation method, it is concluded that the liquefaction resistance of sandy-gravel mixtures, may be taken as equal to - that of clean sands with the void ratio equal to the nominal void ratio of the sand-gravel mixture eo, or - about 2.5 that of clean sands with the void ratio equal to the void ratio of the gravel skeleton esk. The second approach may be more cumbersome to apply, as it requires computation of the esk (based on eo and grain size distribution). Nevertheless, it is associated with lower scatter of the experimental data.

## NUMERICAL ANALYSIS OF GEO-STRUCTURES IN A LIQUEFACTION REGIME – ID 1245

*K. Andrianopoulos, N.T.U.A., Greece*
*A. Papadimitriou, N.T.U.A., Greece*
*G. Bouckovalas, N.T.U.A., Greece*

Currently available commercial codes for the analysis of boundary value problems are not suitable for the simulation of the response of geo-structures in a liquefaction regime. This is mainly due to the fact that the constitutive models available for use in these codes are not appropriate for the simulation of the cyclic behavior of soils. Hence, such problems are usually solved with empirical or approximate numerical methods, since the specialized codes developed in research institutes have usually a narrow range of applicability.

This paper presents a new code for the numerical analysis of the response of geo-structures, with special emphasis given to earthquake-induced liquefaction. The proposed code aims at covering the foregoing gap between commercial and specialized codes. This is achieved by implementing a realistic constitutive model of the mechanical behavior of non cohesive soils to FLAC, i.e. a commercial finite difference code for 2D analysis that is widely used in Earthquake Geotechnical Engineering. Since FLAC is capable of performing coupled dynamic analyses, its use with a realistic constitutive model greatly enhances its potential.

The first part of the paper presents the proposed elasto-plastic constitutive model, namely a bounding surface critical state model that aims at the realistic simulation of the behavior of non cohesive soils under monotonic and cyclic loading. Of great importance is the fact that these realistic simulations are attained by a single set of model constants, for small, medium and large cyclic strains,

irrespective of density, stress level, loading direction and drainage conditions.

The second part of the paper presents results from the calibration and validation procedure of the proposed constitutive model towards the behavior of Nevada (fine) sand in element and centrifuge tests. The necessity of performing coupled analyses with the aid of a realistic constitutive model in Geotechnical Earthquake Engineering problems is highlighted.

### THE EFFECTS OF INITIAL STATIC SHEAR STRESS ON THE LIQUEFACTION POTENTIAL OF A UNIFORM SAND – ID 1403

*S. M. Haeri, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Khosh Ghalb, Sharif University of Technology, Iran (Islamic Republic Of)*

In this paper the results of a research on the effects of initial static shear stress on liquefaction resistance of Babolsar Sand are reported. The studied sand is uniform and can be classified as SP, according to the Unified Soil Classification System. In this study Cyclic Triaxial Tests were performed on cylindrical specimens of uniform saturated sand with a diameter of 50 mm and height of 100 mm. The specimens tested in this study, were prepared for desired density using wet-tamping method. A series of cyclic strain-controlled tests were conducted on Babolsar Sand with two different relative densities of 30% and 50%. The cyclic double amplitude axial strain during all tests was maintained at 0.5%. When the pore pressure parameter (ru) equaled to the unity, the number of cycles was recorded for defining the initial liquefaction. Three different effective isotropic confining pressures of 80, 150 and 250 kPa and three different initial static shear stress ratios (initial static shear stress divided by initial confining effective stress) of 0, 0.76 and 1.3 were considered as the variables for this set of tests. The results show that with increasing initial static shear stress ratio, liquefaction resistance decreases for the loose sand. For the medium dense sand, increasing initial static shear stress ratio has no significant effect on liquefaction resistance of the tested sand, although in low confining pressures, a general increase in liquefaction resistance of this type of sand can be observed.

Keywords: Liquefaction, Initial static shear stress, Sand, Cyclic Triaxial Test

## ES 1-III: Geotechnical Engineering

Thursday 13:30 - 15:00 – Room 21

### A FULL SEISMIC SOIL-FOUNDATION-STRUCTURE INTERACTION APPROACH – ID 421

*M. M. Buehler, Bodenmechanik und Felsmechanik, Germany*
*H. Wienbroer, Bodenmechanik und Felsmechanik, Germany*
*D. Rebstock, Bodenmechanik und Felsmechanik, Germany*
*G. Huber, Bodenmechanik und Felsmechanik, Germany*

In the scope of the Collaborative Research Centre (CRC 461) 'Strong Earthquakes: A Challenge for Geosciences and Civil Engineering' a multidisciplinary attempt towards earthquake mitigation has been made by closing the gap between geotechnical and structural earthquake engineering.

A seismic soil-foundation-structure interaction (SFSI) analysis using FEM has been carried out to investigate the behaviour of a reinforced concrete frame structure founded on a liquefiable soil. Different types of foundations have been investigated. By means of the presented direct SFSI approach, it is possible to determine the influence of local site effects on the ground response, considering the soil type, state (i.e. density, pressure, and remnant of loading history), and earthquake characteristics as well as geological and hydrogeological peculiarities. The calculations were performed with the hypoplastic constitutive law for the soil.

The method is capable to investigate the vulnerability of foundations and their superstructures, in particular the susceptibility against liquefaction of the soil in the vicinity of the foundation, and its consequence for the behaviour of the foundation as well as the dynamic response of the structure. Thus, stability and serviceability (i.e. permanent displacements and tilting, and excessive soil movements in the vicinity) of different types of structures and foundations, as well as the success of soil improvement measures, can be systematically investigated. Based on the outcomes the engineer is able to decide, which type of foundation and structure adjusts better to the local site conditions and, subsequently, an adaptive design can lead to optimised foundations.

### SEISMIC RESPONSE OF TUNNELS IN NEAR-FAULT CONDITIONS – ID 998

*M. Corigliano, Politecnico di Torino, Italy*
*C. Lai, EUCENTRE, Italy*
*G. Barla, Politecnico di Torino, Italy*

The growing need to enlarge the transportation networks throughout railway, motorways and lifelines occurring in the latest years, has spurred a renewed interest for studying the vulnerability of tunnels to earthquake loading. Often these represent the most critical components of the network and the occurrence of an earthquake would not only determine a potential loss of human lives but also damages to the infrastructures. The seismic response of tunnels is considerably different from that of on-ground structures since the overall mass of the structure is usually small compared with the mass of the surrounding soil and the overall confinement acts as a strong damper of the seismic excitation. This is the reason why tunnels are usually considered less vulnerable to the earthquakes compared with on-ground structures. There are however exceptions to this rule, the most notably of which is represented by tunnels located close a seismically active faults as demonstrated by the recent 1995 Japan, 1999 Taiwan and Turkey earthquakes where several tunnels have suffered severe damages. This happens because the ground motion close to an active fault is characterized by strong intensity and relatively short duration (pulse-like motion) and it possesses peculiar features like being strongly affected by focal mechanism, direction of rupture propagation relative to the site and by permanent ground displacement. Assessing the seismic response of tunnels is a complex problem, which may be considerably simplified by uncoupling the task of defining seismic excitation from the solution of dynamic soil-structure interaction. This paper proposes a simplified approach in studying the seismic response of tunnels which takes into account the kinematic interaction of the tunnels and at the same time adequately consider the features of near-fault motion. The proposed approach has been compared with existing methods and with more rigorous analyses. The results of this comparison are encouraging.

### MITIGATION OF EXISTING STRUCTURES USING A "SOFT-CAISSON"-NUMERICAL MODELING – ID 1098

*D. Pitilakis, Ecole Centrale Paris, France*
*F. Lopez-Caballero, Ecole Centrale Paris, France*
*A. Modaressi, Ecole Centrale Paris, France*
*D. Clouteau, Ecole Centrale Paris, France*

Existing structures may suffer during earthquakes due to the lack of sufficient seismic design at the time of their conception. Large acceleration and displacement amplitudes can induce increased seismic forces in the structure, leading to possible failure of the structural elements. In this paper a mitigation scheme is proposed, implementing a caisson of soft-material vertical inclusions surrounding the foundation and a soft soil layer beneath the surrounded foundation soil. The so-called soft–caisson isolates the foundation soil adjacent to the foundation by filtering the frequency content of the input signal beyond a target cut–off frequency, leading to a reduction in the amplitude of the acceleration which enters the structure. The soft–caisson is shown to act beneficially for the structure, for common types of soil–structure systems and earthquake input motions. In order to demonstrate the effects of the proposed mitigation scheme on the structural response, a finite

element numerical code is used along with a numerical code that performs linear soil–structure interaction analysis. In that way, all the aspects of the dynamic response of the complete soil–structure system are included in the analysis. The numerical model is validated with experimental data from shaking table tests. A simple single–degree–of–freedom structural model and a simplified soil profile are then used for the modeling of the structure and the soil respectively. A parametric study is performed, concerning the effects of the stiffness of the vertical inclusions on the structural response. The response obtained with the proposed mitigation method is always compared with the response of the system prior to the intervention, revealing the benefits, but also the restrictions and technical limitations, of the mitigation scheme.

### INVESTIGATION OF THE SEISMIC SOIL-STRUCTURE INTERACTION ON A CONCRETE INSTRUMENTED BUILDING – ID 1105

*J. Facciorusso, Civil Engineering Dept., University of Firenze, Italy*
*T. Crespellani, Civil Engineering Dept., University of Firenze, Italy*
*C. Madiai, Civil Engineering Dept., University of Firenze, Italy*

Experience has shown that soil-structure interaction can play an important role on structural behaviour during earthquakes. A complete soil-structure interaction analysis consists of two parts: a site response analysis for free field motions and an interaction analysis for structural response. In the present study the effects of soil-structure interaction are evaluated on a two-store concrete building of about 10 m high and with a rectangular horizontal section of about 11 m x18 m. The building, of public interest, is equipped with several accelerometers. The structure and the foundation system are idealised by a 3-D finite elements model, while the underlying soil was represented by a semi-infinite visco-elastic 1-D model. The soil-structure interaction was performed by using the substructuring method implemented by the SASSI 2000 numerical code. The accelerograms recorded during a low magnitude earthquake (ML = 4) by a free field seismic station, 5m close to the building, were adopted as the seismic input motion. In this paper the results of the numerical analyses obtained in some significant nodes of the structure are presented both in time and frequency domain, and compared with the seismic recordings; moreover the influence of the structure on the ground motion is evaluated by comparing the free field actual motion with the numerical modelling results at the boundary between the soil and the foundation.

### STRUCTURE SOIL STRUCTURE INTERACTION: EXPERIMENTAL AND THEORETICAL RESULTS – ID 1247

*D. Broc, CEA, France*

In nuclear industry, sizes and masses of structures are such that Soil Structure Interaction (SSI) will take place. It is necessary to quantify the Structure Soil Structure Interaction (SSSI), that consider the interactions between two adjacent buildings. A reactor building of a nuclear power plant is generally constructed closely to other buildings such as auxiliary building or turbine building. In such situations, adjacent buildings are thought to influence each other through the soil during earthquake and to exhibit dynamic behaviours different from those of isolated buildings.

The paper presents Structure Soil Structure Interaction studies performed by CEA and EdF, based on the interpretation of in situ tests performed by NUPEC in Japan, and on theoretical analysis.

The field test experiments have been carried out by NUPEC (JNES) under different conditions (1) with one building, two identical buildings or two different buildings (2) in an excavation, for the "surface configuration", and in the "embedded configuration", when the excavation is filled. Forced vibration test and earthquake observations are being carried out in the field test. NUPEC proposed a theoretical model for the interpretation of the experimental results, including soil and buildings mechanical characteristics. The results obtained by this model are similar to the experimental ones.

CEA and EdF developed sensibility analyses, based on the NUPEC theoretical model, for the forced vibration tests. The most important elements obtained are: (1) the stiffness of the soil layer situated immediately below the buildings is the main parameter governing the dynamic behaviour of the system (2) the results are sensitive to the conditions of the contact between the soil and the buildings, in the embedded configurations (3) in the "surface configuration", the results do not depend on the position of the buildings in the excavation.

### EFFECT OF RANDOM SOIL PROPERTIES ON SOIL-STRUCTURE INTERACTION – ID 1323

*F. Laudarin, Université de Marne la Vallée, France*
*G. Bonnet, Université de Marne la Vallée, France*
*P. Argoul, Ecole Nationale des Ponts et Chaussées, France*

Usually, the seismic behavior of a structure is assessed using either fixed foundation computation or a deterministic evaluation of the soil impedance. At best, the soil variability is taken into account by using a few values of soil elastic moduli, the soil being assumed homogeneous in the horizontal directions. A few papers have shown however that the horizontal soil variability can lead to specific effects, such as torsion , even for a building with symmetric geometry.

The paper is devoted to the evaluation of the influence of such a horizontal variability of the soil properties on the dynamic behavior of structures. Structures are represented by equivalent one-dimension models whose properties are computed according to the geometry and mechanical properties of existing structures :

- an equivalent homogeneous Timoshenko or Euler-Bernoulli beam par - a beam with mass concentrated at each floor level

The impedance of the foundation is modeled by a probabilistic non-parametric model. Such a model is based on the principle of maximal entropy and implies to take into account only the available information. The mean value of the impedance is computed from an estimation of the soil properties and usual computations of the impedance matrix. A Monte-Carlo method allows to build a series of impedance matrices which are compatible with the probability distribution of the non-parametric model. The probability distribution is controlled by a dispersion parameter, which can be estimated from the observed variability of soil properties.

Finally, the internal forces and moments within the structure, including the related dispersion induced by the probabilistic model, are computed by modal analysis , when the structure is under earthquake loads.

## ES 1-IV: Geotechnical Engineering

Thursday 15:30 - 17:00 – Room 21

### EFFECTS OF TWO-DIMENSIONAL SHAKING ON SOIL-PILE-STRUCTURE INTERACTION BASED ON SHAKING TABLE TESTS – ID 954

*H. Suzuki, Tokyo Institute of Technology, Japan*
*K. Tokimatsu, Tokyo Institute of Technology, Japan*
*Y. Mohri, National Institute of Rural Engineering, Japan*
*M. Sato, National Research Institute for Earth Science and, Japan*

Effects of two-dimensional shaking on soil-pile-structure interaction during earthquakes are examined through shaking table tests with a cylindrical laminar box 1.8 m in diameter and 1.35 m high. A 2x2 pile group that penetrates either dry or liquefiable saturated sand and supports a foundation and a superstructure is used throughout the tests. Either one or both of the orthogonal horizontal strong motions recorded at Hachinohe Harbor in the 1968 Tokachi Earthquake are used as input base motions.

Test results and discussions lead to the following conclusions: 1) The maximum bending moment and axial force in piles caused by the two-dimensional shaking can be estimated by the sum of those obtained by applying the two orthogonal components separately. The maximum bending moment depends only on the

maximum combined external (inertial and kinematic) force in the two-dimensional horizontal plane, regardless of the direction of its strong axis, resulting in almost the same value within the pile group. In contrast, the maximum axial force depends not only on the maximum combined external force but also on the direction of its strong axis, inducing different axial forces within the pile group. 2) In dry sand, the soil near the foundation tends to act against the inertial force from the superstructure. The maximum axial force is almost controlled by the overturning moment that is induced by the maximum inertial force in the horizontal plane, with its rotational axis near the bottom of the foundation. 3) In liquefied sand, in contrast, the kinematic force arising from the ground displacement tends to act with the inertial force. The maximum axial force is controlled by the overturning moment that is induced by the maximum combined inertial and kinematic force in the horizontal plane, with its rotational axis near the bottom of the liquefied layer.

## TWO DIRECTIONAL CYCLIC LOADING EXPERIMENTS IN A HOLLOW CYLINDER APPARATUS – ID 1006

*J. Buchheister, Institute for Geotechnical Engineering, ETH Zurich, Switzerland*
*J. Dr. Laue, Institute for Geotechnical Engineering, ETH Zurich, Switzerland*

In earthquake engineering the investigated stress state simulated in the laboratory is often adapted to available testing instruments. Generally this includes cyclic or earthquake loading in one direction. With the new hollow cylinder apparatus of the Institute for Geotechnical Engineering at the Swiss Federal Institute of Technology (ETH) it is possible to adjust any possible stress state in the soil prior of testing. This allows investigating different stress states in the soil that exists underneath a building. Experiments with fine sand are investigated to simulate three different stress states underneath a building under simultaneously two directional cyclic loading. Primary results are presented focusing on the influence of stress state and two directional cyclic loading to be considered in soil structure interaction.

## MONOTONIC AND CYCLIC UNDRAINED RESPONSE OF BOCA DEL RIO SAND – ID 1043

*J. A. Díaz-Rodríguez, National University of Mexico, Mexico*
*M. A. Aguilar-Téllez, National University of Mexico, Mexico*

In recent decades, study of the behavior of saturated loose sand under undrained monotonic and cyclic conditions is a matter of concern to the geotechnical engineers from viewpoint of liquefaction susceptibility. In this paper an attempt is made to present a comprehensive picture of monotonic and cyclic loading response of Boca del Río sand covering a wide range of initial states of sand in order to consider a full spectrum of monotonic loading behavior from contractive to dilative and its close link with development of liquefaction or limited liquefaction and cyclic mobility under cyclic loading.

The behavior of Boca del Rio sand was investigated by monotonic and cyclic tests using the simple shear apparatus, over a wide range of initial states. Specimens were prepared by air pluviation at several relative densities. The simple shear apparatus utilized was of the Norwegian Geotechnical Institute (NGI) type. It accommodates a specimen 71 mm diameter x approximately 25 mm high. The specimen is laterally confined in a reinforced rubber membrane. The undrained tests carried out were of the constant volume type.

The sand behavior at fixed vertical stress level of 100kPa, at the loosed void ratio of 0.928, the sand is contractive with a brittleness index of about 0.16. As the void ratio decreases, the contractive behavior gradually transform into dilative. The sand behavior at a single void ratio of 0.928 but at several vertical stress levels is contractive for all vertical stresses used.

Cyclic tests were performed at different void ratios and vertical stress levels of 50, 65, and 80 kPa. The effect of vertical stress on the reduction in cyclic resistance is much smaller than currently considered in Practice.

## PHYSICAL MODELLING OF EARTHQUAKES IN THE LCPC CENTRIFUGE – ID 1064

*J. L. Chazelas, LCPC, France*
*F. Derkx, LCPC, France*
*L. Thorel, LCPC, France*
*S. Escoffier, LCPC, France*
*G. Rault, LCPC, France*
*S. Buttigieg, LCPC, France*
*L. M. Cottineau, LCPC, France*
*J. Garnier, LCPC, France*

In order to contribute to the development of earthquake engineering in Europe, LCPC has completed the equipment of its geotechnical centrifuge an earthquake simulator for reduced scale models. Dynamic and seismic tests under macro gravity in the centrifuge are henceforth operational. This paper presents this device and other peripheral that, combined together, enable the physical simulation of real earthquakes.

As for earthquake modelling, the payload mass is up to 400kg and the EQS is able to work up to 80G. The soil model is up to 800x300x400mm, that is to say 64x24x32m at 80G. The EQS is a 1D electro-hydraulic shaker dynamically balanced using two slip tables, counterweights for balancing the model motion and close loop control of the hydraulic actuators. It produces 1 second harmonic inputs or broad band or real earthquake inputs derived from on site records at the basis of the soil model. The theoretical bandwidth of the system is from 20Hz to 250Hz (model scale which is 0,25Hz to 3Hz at prototype scale for 1/80e scaling). The maximum bandwidth depends on the type of input demanded and on the gravity level of the test. Examples of tests for these different kinds of inputs are presented.

In order to reproduce the seismic behaviour of the soil model in its original infinite half space, a specific box has been developed on the principle of the Equivalent Shear Beam box for tests under the liquefaction point. A discussion of the validity of the obtained seismic performance is presented.

Last element to complete the panoply of devices aimed at earthquake simulation in the centrifuge: an original data acquisition system embarked in the swinging basket of the centrifuge. Adapted to macro gravity this device reduces the distance between the sensors and the A/D conversion, avoiding EM perturbations.

## EXPERIMENTAL OBSERVATION AND THEORETICAL CALCULATION OF TECHNICALLY INDUCED SURFACE WAVES IN INHOMOGENEOUS SOIL – ID 1292

*L. Auersch, Federal Institute of Material Research and Testing, Germany*

The propagation of surface waves is an important topic of seismology. The theory is based on the Green's functions of layered soil. The same Green's functions are also used to calculate the stiffness and damping of building foundation. This problem - also called soil-structure interaction – is important in earthquake engineering. For both related problems – wave propagation and foundation stiffness – a lot of measurements have been performed. The results have been compared with theory and show a considerable agreement. But there are some characteristic differences between experiments and theory which will be presented in this contribution. The effects have been observed for technically excited vibration as for example pile driving, railway traffic and hammer excitation. Similar differences between measurements and theory are also found for earthquake excitation. But the possible reasons for certain high-frequency filter effects are still in discussion. The technically generated phenomena presented here can help at this discussion because of the much simpler structure of the problem. At least, the complicated source problem of earthquakes is reduced to a simple vertical surface force for technically induced vibration. Moreover, the same response of the soil is found for an impulse excitation of a 5 kg hammer as well as for an electro-dynamic vibrator of 300 kg. The measured and calculated transfer functions of the soil are successfully used to predict rail-traffic induced ground vibration. Concerning the

soil-structure interaction problem, a solution is presented for the difference between the foundation stiffness and the measured soil stiffness. The calculation of foundations on soils of which the stiffness is increasing with depth show that the stiffness of the soil is overestimated when it is measured at frequencies around the low-frequency soil-structure resonance. The dispersion of these inhomogeneous soils is important to achieve a correct prediction of the soil-structure interaction.

### CENTRIFUGE MODELING OF SEISMIC RESPONSE OF CLAY – ID 1456

*M. Rayhani, UWO, Canada*
*H. El Naggar, UWO, Canada*

Centrifuge modeling is a valuable means for obtaining data to study the response of geotechnical structures to infrequent or extreme events such as earthquakes. Centrifuge model tests were conducted in 80g field using an electro-hydraulic earthquake simulator to study the dynamic response of soft soils and seismic soil structure interaction. The results of study of four different soft soil profiles subjected to 23 simulated earthquakes on the C-CORE geotechnical centrifuge are presented and analyzed. The effect of soft soil on earthquake ground motion in different types of soil stratifications are investigated with special emphasis on the seismic soil structure interaction. The site specific response and soil shear strength data for the models are presented. The tests showed that the effects of the layering of the soil deposits on the input motions and overall behavior of structure are significant. The experimental results provided improved confidence in our ability to model site response characteristics of soft soil deposits.

## ES 2: Dam Engineering

Friday 13:30 - 15:00 – Room 21

### DYNAMIC EXPERIMENT OF A LARGE ARCH DAM – ID 202

*H. Wang, China Institute of Water Resources and Hydropower, China*
*D. Li, China Institute of Water Resources and Hydropower, China*

Seismic safety of large arch dams presents a difficult problem in design; it is one of the biggest challenges in the development of hydropower in southwest and northwest area of China. In our study, seismic responses of a large arch dam of 210 meters in height were studied on a shaking table. The model system included the arch dam with contraction joints, part of reservoir upstream, partial foundation rock with topographic feature near the dam. A damping boundary consisting of viscous liquid were used to simulate the effect of dynamic energy emission to far field, which made the dynamic interaction between dam and foundation in model arch dam system be represented properly. Besides the seismic motions of design level, higher seismic motions up to 4.5 times of design level were applied too in order to examine the damage developed on the model dam. 10 damages have been confirmed at final stage. And the dynamic characteristics of the arch dam, ability of seismic resistance to stronger ground motion as well as the seismic vulnerable positions of dam are discussed in the paper.

### A COMPARISON OF RECORDED AND COMPUTED EARTHQUAKE MOTIONS OF LARGE CONCRETE DAMS – ID 627

*J. Proulx, Université de Sherbrooke, Canada*
*G. Darbre, Office fédéral de l'énerige, Switzerland*

This paper presents recorded earthquake motions on large concrete dams, among the tallest in the world, located in the southwest of Switzerland (Mauvoisin, h=250 m and; Emosson, h=180 m; and Grande-Dixence, h=285 m). The accelerations were recently recorded during a moderate earthquake that occurred in the vicinity of the dams.

Three dimensional numerical models were prepared for the dam-reservoir-foundation systems and were calibrated on the basis of previous, extensive in-situ forced and ambient vibration dynamic tests. The calibration parameters included concrete modulus and energy dissipation in the upstream direction (water compressibility) and on the reservoir bottom (wave absorption). These models were then used to compute the acceleration responses of the dam, using the recorded free-field motions as ground motion input, and compared to actual recorded data.

In a previous study using different recorded motions, it was found that high damping values (8 to 15% of critical) were needed with a massless foundation approach to correlate with the motions recorded at the dams. Using an energy dissipating foundation model, damping in the dam was kept at a reasonable level (3 to 4 % of critical) and values of up to 20% of critical were needed in the foundation model. These high values were attributed to the averaging of the input motions along the abutments and to energy dissipation in the foundation.

In this paper, a comparison is presented between recent earthquake data, recorded in September 2005, with stronger motions (up to 0.7 of g for Emosson dam, closest to the epicenter), and data obtained during smaller events. The modelling parameters needed to corroborate the computed responses with the recorded accelerations are discussed, with an emphasis on foundation damping.

### VERIFICATION OF 3-D SEISMIC SAFETY EVALUATION METHOD FOR EXISTING DAMS BY REPRODUCTION ANALYSIS FOR ACTUAL EARTHQUAKE BEHAVIOR – ID 1214

*L. Alcántara, Engineering Institute, UNAM, Mexico*
*Y. Ariga, Electric Power Development Co., Ltd., Japan*

Confirmation and securing of dam safety against large earthquakes is very important subject in earthquake countries. In order to realize an accurate and reliable evaluation for seismic safety of existing dams, a dynamic interaction between dam and foundation, a dynamic reduction effect by reservoir water, a dissipation of wave energy from foundation to free field, a non-linear effect of dam material, a discontinuous behavior of joints, and so forth should be considered properly. The dynamic property values of dam and foundation will have significant effects upon the evaluated results of dynamic stresses and strains, so the dynamic property values should be qualitatively evaluated based on actual earthquake phenomena. Efficiency and validity of seismic safety evaluation method should be verified based on actual earthquake phenomena. Taking these matters into account, I developed a 3-D nonlinear dynamic analysis method for a coupled dam-joints-foundation-reservoir system. And, in order to verify the validity of the method, I have made the 3-D reproduction analyses for actual earthquake behaviors of the Nukabira Dam (concrete gravity dam) during the 1993 Kushiro-oki Earthquake, the Ikehara Dam (concrete arch dam) during the 1995 Hyogoken-nanbu Earthquake, the Shintoyone Dam (concrete arch dam) during the 1997 near-field earthquake, and the Tagokura Dam during the 2004 Niigataken-chuetsu Earthquake, and so forth. By these 3-D reproduction analyses, the values of dynamic shear modulus and the damping factor of dams were evaluated quantitatively, and the efficiency and validity of the 3-D dynamic analysis method were examined. The 3-D reproduction analysis for actual earthquake behavior of existing dams is necessary and useful in order to verify the validity of the 3-D seismic safety evaluation method, and to realize an accurate and reliable evaluation for seismic safety against large earthquakes in the future.An effective utilization of actual earthquake motions is very important.

### DYNAMIC STABILITY OF DETACHED CONCRETE BLOCKS IN ARCH DAM SUBJECTED TO STRONG GROUND SHAKING – ID 1305

*S. Malla, Electrowatt-Ekono Ltd., Switzerland*
*M. Wieland, Electrowatt-Ekono Ltd., Switzerland*

During strong ground shaking, tensile stresses exceeding the dynamic tensile strength occur in the central upper portion of an arch dam. As the tensile strength of the grouted vertical contraction joints and the horizontal lift joints is inferior to that of the parent mass concrete, the contraction joints may open and horizontal cracks are more likely to develop along the lift joints. Thus, almost independent concrete blocks separated by the open joints and cracks may be formed. The present paper discusses a simple approach for a two-dimensional dynamic stability analysis of a detached concrete block formed in an arch dam during a strong earthquake. The detached concrete block can undergo combined sliding and rocking motions at the cracked lift joint, which is modelled with contact elements. Because of the arch curvature, the detached concrete block can move only towards the reservoir. Hence, the downstream movement of the concrete block is restrained by means of gap elements in the two-dimensional model. The restraint at the contraction joints due to the shear keys is ignored, which is a conservative assumption. The proposed method was applied to analyse the stability of two detached concrete blocks with heights of 20 m and 40 m in a 250 m high arch dam subjected to the maximum credible earthquake. As several factors play a role in the dynamic stability of the blocks, comprehensive sensitivity analyses were performed. The largest upstream sliding movement of 105 cm was computed for the 20 m high block in the empty reservoir condition. Such a movement is still acceptable in view of the conservative assumptions made in the analysis and also the fact that the dam thickness at the location of the sliding surface is about 17 m.

### THREE DIMENSIONAL RESPONSE OF CONCRETE FACED ROCKFILL DAMS TO STRONG EARTHQUAKES CONSIDERING DAM-FOUNDATION INTERACTION AND SPATIAL VARIABLE GROUND MOTION – ID 1406

*S. M. Haeri, Sharif University of Technology, Iran (Islamic Republic Of)*
*M. Karimi, IOEC, Iran (Islamic Republic Of)*

A new approach based on scaled boundary finite element method is used to obtain scattered motion along a prismatic canyon with trapezoidal cross section. The time history of three components of Loma Prieta earthquake (Station Gilroy1) are used as coherent input excitations to get the spatial variation of ground motion in the valley. Then the results are used as input motion for 3D dynamic analysis of a typical Concrete Faced Rockfill Dam (CFRD) located in the canyon. In addition dam-face slab-abutments interaction is considered in the analysis using scaled boundary-finite element method. The results of a parametric study with different canyon stiffness show that due to dam-foundation interaction, maximum abutments out-of-phase motion happens in a specific relative stiffness of canyon and the dam body. Results of the analysis also indicate that the displacements and accelerations of the dam body and the slab as well as the internal forces of the slab are increased due to the out-of-phase motion of the abutments. However, consideration of dam-foundation interaction can reduce these values. The internal forces and out-of-plane relative displacements of the slabs during earthquakes are considerably high even with consideration of dam-foundation interaction.

### NEEDS FOR SEISMIC SAFETY EVALUATION OF DAMS – ID 1487

*T. Ohmachi, Tokyo Institute of Technology, Japan*

In Japan, "Guidelines for Seismic Safety Evaluation of Dams Subjected to Level 2 Earthquake Motions (Draft)" came into effect in March, 2004. The Guidelines which was issued by the Ministry of Land, Infrastructure and Transport (MLIT), aims to ensure the seismic safety of dams against very strong shaking called Level 2 (L2) earthquake motions. The Guidelines states requirements, concepts and procedures to evaluate the L2 motion, analytical methods to evaluate seismic performance of concrete dams, fill dams and other pertinent structures such as spillways and flushing gates. Meanwhile, several fill dams located in and around the near field of the Niigata-ken Chuetsu earthquake (MJ6.8), Japan that occurred on October 23, 2004 were more or less damaged. Among them, Shin-yamamoto Dam which is 42.4m high, completed in 1990, suffered maximum settlement of the crest exceeding 80cm and sand liquefaction. Thick sedimentation in front of the drain layer is presumably responsible for the liquefaction. The earthquake damage demonstrated the urgent necessity of application of the Guidelines throughout Japan.

## ES 3a-I: Structural Engineering - Analysis
Wednesday 10:45 - 12:15 – Room 22

### ASSESSMENT OF RC STRUCTURES DESIGNED ACCORDING WITH 1983 PORTUGUESE SEISMO-RESISTANCE REGULATION – ID 138

*M. J. Falcão Silva, LNEC, Portugal*
*A. Campos Costa, LNEC, Portugal*
*E. Coelho, LNEC, Portugal*

The seismic vulnerability of the Portuguese housing stock results from many different factors, namely the original constructive technology, the introduction of subsequent modifications and the state of degradation. Based on the existing constructive types observed in the areas of large seismicity and urban concentration it was possible to identify the more frequent and representative constructions of the Portuguese housing stock. To each class of building two main vulnerability factors were associated, the construction epoch and the structural type, which reflect the main structural and mechanical characteristics of each class of buildings. In the present study the construction epoch was considered as basic vulnerability factor and it were distinguished the constructions designed before and after the implementation of the sismo-resistant regulation in Portugal. This study refers to the analytical simulations of the reinforced concrete buildings designed in accordance with the Portuguese regulation. In the simplified analytical models were used 2D frames representative of Portuguese symmetrical regular structures, considering the changeable factors the number of storeys and the ductility demands. Non-linear static analysis, with forces proportional to the shape of the first vibration mode, had been made in order to identify the resistant capacity of the more recent Portuguese building structures. The corresponding capacity curves are obtained and compared.

### DAMPING FACTORS AND EQUIVALENT SDOF DEFINITION IN THE PERFORMANCE-BASED ASSESSMENT OF MONUMENTS – ID 258

*S. Giovinazzi, DISEG, University of Genoa, Italy*
*S. Lagomarsino, DISEG, University of Genoa, Italy*
*S. Resemini, DISEG, University of Genoa, Italy*

The recent Italian seismic decrees (OPCM 3274/2003 and OPCM 3431/2005) have strongly modified the safety concept for existing buildings. This code introduces the idea of design and verification through performance-based analysis. Unfortunately, in case of monumental heritage, the OPCM 3274 decree does not propose a specific methodology, even though it points out the need for a quantitative evaluation. Even basing the safety check on the same concepts and procedures, various issues have to be pointed out. In this paper, the definition of the equivalent SDOF system (to be employed in the performance-based method) in case of characteristic conformations of monumental masonry buildings (e.g., façades or bell towers) and the dynamic response peculiarities of these structures are deepened. For masonry historical structures, the available literature on this topic generally deals with the out-of-plane overturning mechanism, considering the wall as an oscillating rigid block (e.g., façades or bell towers). As a matter of fact, for these structures, the fundamental periods are large, even in the initial elastic range, and they can increase because of

cracking in masonry, typically considered as no-tension material. The effects of these features on the dynamic response and the related prediction of displacement capacity need to be investigated. For this purpose, non-linear dynamic analyses on the equivalent SDOF systems are performed, employing different input ground motions. These analyses may be useful to evaluate the influence of factors such as: 1) the feasibility of the equivalent SDOF system definition (as for mainly rocking system, the model is derived by Housner's non-linear oscillator, having elastic behaviour, with softening range); 2) the equivalent viscous damping relationship and the consequent Displacement Response Spectrum reduction in the long-period range (due to the non-linear characteristics of motion); 3) the duration of the seismic input and the number of cycles in non-linear phase.

### STATISTICAL EVALUATION OF CRITICAL INTER-STOREY DRIFT CONCENTRATION OF RC FRAMES – ID 288

*Y. Lu, Nanyang Technological University, Singapore*
*X. Gu, Nanyang Technological University, Singapore*
*J. Wei, Nanyang Technological University, Singapore*

In performance based design, the evaluation of displacement (drift) demand in a structure is a crucial aspect. Simplified analyses may be performed to estimate the overall drift demand in a frame structure from the displacement spectrum of single-degree-of-freedom (SDOF) systems. However, apart from the overall drift information (usually in terms of roof displacement), it is also important to understand the critical inter-storey drift as compared to the roof drift so as to have a better picture on the concentration of the inelastic response and damage. Hence, the relationship between the critical inter-storey drift and the roof drift is an important parameter for a more effective use of a simplified analysis procedure using SDOF analogy. In this paper, a modified approach is proposed to evaluate the regularity of the storey strength and stiffness distribution along the frame height, with the introduction of a storey "capacity" factor. Subsequently, the relationship between the regularity index defined on the basis of the above storey capacity factor and the ratio of critical inter-storey drift to roof drift is investigated through the nonlinear dynamic analysis of several representative RC frames under selected groups of ground motions. Besides the regularity index, the effects of nonlinear response level and the number of storeys on the inter-storey drift concentration are also examined. It is found that the concentration ratio has a good correlation with the newly-defined regularity index. Based on a regression analysis, an empirical relationship is proposed to describe the relationship between the drift concentration ratio and the regularity index.

### SEISMIC BEHAVIOUR OF RC STRUCTURES : REVIEW OF THE PRINCIPAL MODELLING STRATEGIES – ID 241

*L. A. M. Mendes, National Laboratory of Civil Engineering, Portugal*
*E. Coelho, National Laboratory of Civil Engineering, Portugal*

The main goal of this paper is to review the characteristics of the behaviour of RC structures subjected to seismic or dynamic loads, in order to identify the most adequate strategies for modelling the response. The principal models used for almost two decades of studies in this area are discussed. The paper begins with some general aspects of the materials behaviour. For the concrete the effect of multi-axial load conditions and the effect of the strain rate are discussed, followed by modelling techniques: damage models; plasticity models and some concepts of fracture mechanics. Afterwards the principal characteristics of the steel used in reinforced bars are presented and the more commonly used models are reviewed. An entire section is dedicated to the behaviour of steel-concrete and concrete-concrete interfaces, which can influence greatly the overall performance of the structure. The problem of bond deterioration is presented with the qualitative analysis of results from available pull-out and cyclic tests. The most used strategies to model these effects are also discussed. For the concrete-concrete interfaces, where continuity can not be assumed (e.g. through cracks or construction joints) the principal mechanisms for load transmission are focused, which are the aggregate interlock, dowel action and aggregate debonding. The behaviour of RC members subjected to bending, with and without axial force, and to high shear forces is discussed. Some considerations about beam-column joints and other local effects, like cover spalling and reinforcement buckling, are briefly covered. Furthermore the main characteristics, advantages and disadvantages of the modelling techniques are discussed: global behaviour models (e.g. Takeda model), fibre models and the extremely complex but powerful 3D finite element models. Finally the conclusions of this paper are summarised, expressing the author's opinion on the most adequate procedures for modelling the seismic response of RC structures.

### INELASTIC MODELING SENSITIVITY OF THE PREDICTED SEISMIC PERFORMANCE OF AN EXISTING RC BUILDING – ID 980

*C. Zeris, NTUA, Greece*
*P. Giannitsas, NTUA, Greece*
*K. Alexandropoulos, NTUA, Greece*
*D. Vamvatsikos, U. of Cyprus, Cyprus*

Inelastic modeling of entire reinforced concrete (RC) buildings under seismic excitation is a complex problem that directly influences the predicted seismic performance. Modeling assumptions and conventions adopted become more important in existing RC frame response predictions, due to these structures' structural characteristics and detailing.

In order to investigate this issue a typical existing five-story RC frame is considered, which has been designed for moderate seismicity according to the older generation of Greek seismic codes, with no special provisions for ductility enhancement or capacity design. Several engineering decisions must be made when modeling such a structure, especially when choosing the type of finite element (FE) models to be used for the beams, the columns and the joints. For this purpose, different plane frame FE models are formulated using two FE analysis codes of wide applicability, namely DRAIN-2DX (Prakash V. and G. Powell, 1993, UCB/SEMM-93/17) and OpenSees (Mc Kenna F. and G. Fenves, version 2005); the FE models of the structure range from simple yet widely adopted in practice concentrated plasticity elements with rigid joints and axial-flexural strength interaction only (Drain-2DX), to the more complex distributed damage stiffness or flexibility-based fiber elements accounting or not for joint deformations (OpenSees). The predicted seismic performance of each frame is established following both a conventional static pushover as well as nonlinear time-history analyses under a suite of ground motion records applied as-recorded or scaled by a constant factor, thereby estimating the structural response under different levels of seismic intensity.

The analysis results are finally compared at the global and the local damage prediction levels, across all models, to reveal substantial, yet, often ignored errors and wide scatter of the predicted value of key performance indices, which are eventually introduced into the Performance Based Design Approach by the model limitations.

### VALIDATION OF A NEW ANALYTICAL PROCEDURE FOR THE DERIVATION OF VULNERABILITY CURVES – ID 58

*T. Rossetto, University College London, UK*

A new analytical procedure for deriving displacement-based vulnerability curves for classes of buildings, which combines adaptive pushover analyses with a modified capacity assessment technique, was proposed in Rossetto and Elnashai (2005). This paper looks to assess the feasibility of application of the procedure and validity of the vulnerability relationships derived from it. This is done by using the procedure to derive two sets of fragility curves for populations of low-rise bare and masonry infilled reinforced concrete moment-resisting frames designed to old seismic codes, and then comparing these curves with observational damage statistics

for these buildings collected from past earthquake events. The second building type is chosen for the feasibility assessment as the presence of infills and lack of capacity design cause rapid changes in the structures' stiffness with progressive damage and consequently large variations in both its capacity and the seismic demand. However, there are few available observational post-earthquake damage statistics with which to validate the curves derived for this type of structure. Hence, vulnerability curves are also derived for bare frames (or frames with weak infills) for which a more substantial amount of validation data exists. It is shown that the proposed procedure allows vulnerability curves to be generated in a substantially shorter time than conventional methods (adopting non-linear time-history analyses) and results in curves that give a reasonable correlation to past earthquake damage observations.

References Rossetto T, A.S.Elnashai, (2005), "A New Analytical Procedure for the Derivation of Displacement-based Vulnerability Curves for Populations of RC Structures", Engineering Structures, 27(3). 397-409.

## ES 3a-II: Structural Engineering - Analysis

Wednesday 13:30 - 15:00 – Room 22

### CAPACITY CONTROL METHOD FOR SEISMIC ASSESSMENT OF LOW-TO-MEDIUM RISE REINFORCED CONCRETE BUILDINGS – ID 1042

*M. S. Gunay, Middle East Technical University, Turkey*
*H. Sucuoglu, Middle East Technical University, Turkey*

Seismic performance assessment of existing buildings, which were constructed before the advances in earthquake engineering and construction technology, is an important subject that should be handled in a short time. Considering both the size of the problem and the inadequacy of inelastic analysis methods in the seismic evaluation of large building stocks, it is evident that simple and convenient methods are required. A practical and efficient force-based seismic assessment method for low-to-medium rise ordinary reinforced concrete buildings, which employs linear elastic analysis in combination with capacity principles, is developed herein. So called 'Capacity Control Method' consists of identifying the expected locations of inelastic behavior and determination of the member performances by computing force demand-to-capacity ratios (DCR) and comparing them with the DCR limits. Then a decision is made about the building performance, combining the member performances. One important feature of the method is the calculation of the axial forces of the columns by using the shear forces that can be transmitted from the beams at the ultimate limit state. As a by-product of the method, base shear capacity of the building is also calculated. The method is implemented on three case study buildings in order to compare the results with nonlinear time history analysis and nonlinear static (pushover) analysis. Comparisons are based on the distribution of the locations exhibiting inelastic behavior and the member performances. In addition, axial forces and moment capacities of columns and base shear capacities of buildings obtained according to the Capacity Control Method are compared with those obtained from pushover analysis.

### PSEUDO-ENERGY RESPONSE SPECTRA FOR THE EVALUATION OF THE SEISMIC RESPONSE FROM PUSHOVER ANALYSIS – ID 1183

*M. Mezzi, University of Perugia, Italy*
*F. Comodini, University of Perugia, Italy*
*M. Lucarelli, University of Perugia, Italy*
*A. Parducci, University of Perugia, Italy*
*E. Tomassoli, University of Perugia, Italy*

PROBLEM DEFINITION An application of non linear static analysis method through energy approach is based on the idea that the energy of seismic input transferred to the structure is dissipated by the controlled damage of its members. The pushover curve is defined considering that in each step the work of the floor forces is equal to the structure internal work. The pushover curve is expressed in terms of energy capacity and is compared with energy response spectra representative of the seismic input to find the performance point defining the structural response to the design earthquake. The method is illustrated in a separate paper from the same authors. PROPOSED APPROACH The energy capacity curve can be computed directly. The seismic response spectra in terms of energy need some evaluations. Pseudo-energy response spectra must be defined from the energy spectra of the reference earthquakes in such a way that they correspond to the energy demand of the unilateral behaviour typical of pushover analysis. This approach is useful for a variety of aspects: the arbitrary choice of displacement control point is eliminated; the equal-energy capacity curve has physical meaning since its integral is the actual elastic-plastic energy dissipated by the structure; the ductility coefficient computed through the capacity curve is the global ductility of the actual system; the evaluation of the target displacement does not require inelastic constant-ductility or equivalent-damping spectra conventionally derived from elastic spectra. RESULTS AND APPLICATIONS Pseudo-energy spectra are proposed corresponding to the conventional design spectra. Solutions are carried out for some cases of study including both buildings and bridges. The results are compared with those coming from non linear static analyses based on reduced spectra with controlled damping or ductility and from non linear dynamic analyses. The potential application to 3D models with torsion behaviour is investigated.

### STUDY OF LISBON ANTI-SEISMIC DOWN-TOWN QUARTERS – ID 1307

*M. Monteiro, IST, Portugal*
*M. Lopes, ICIST, Portugal*
*R. Bento, ICIST, Portugal*

Lisbon's down-town was rebuilt after the great destruction caused by 1755 earthquake. The buildings have particular characteristics of anti-seismic techniques, improved in the second half of the XVIII century, after the earthquake. Advanced seismic knowledge and construction methods were applied gathering the buildings of a whole quarter to make them respond together to the occurrence of a seismic action. Those buildings are made of external thick masonry walls and in the interior comprise triangulated wood structures, share middle masonry walls and were built with the same size and floor height, according to the original conception. However, many changes have been made since then, adapting building's function to modern activities. Those changes are, among others, the enlargement of typical small rooms by breaking down resistant walls made of triangulated wood structure, construction of additional floors and consequent increase of the structure vibration mass, cut of vertical elements on the ground floor, change of the uniform and regular architecture and the cuts in wooden structure to insert pipe lines. A three dimensional model of an original quarter was created to study its dynamic behaviour and to learn about the buildings interaction. Its seismic response was compared with that of two buildings from the same quarter, analysed separately. A parametric study was then performed i) to quantify consequences of negative interventions, ii) to characterize wood pavement's rigidity and its influence on global stiffness and seismic behaviour, iii) to identify weaker connections between different elements and materials, iv) to learn about interaction of masonry walls and triangulated wood skeleton and v) to support retrofitting interventions.

### VERIFICATION OF IMPROVED PUSHOVER PROCEDURE IRSA (INCREMENTAL RESPONSE SPECTRUM ANALYSIS) – ID 452

*G. Önem, Bogazici University, Turkey*
*M. N. Aydinoglu, Bogazici University, Turkey*

Estimation of inelastic seismic demands on structures requires comprehensive inelastic analysis. While nonlinear response

history analysis (RHA) is the most rigorous analysis tool, it is time consuming and involves a complicated selection of acceleration records. Therefore, practice-oriented nonlinear procedure based mainly on pushover analysis has been recognized in the past decade as the most appropriate tool for the performance-based seismic evaluation of structures. However, standard pushover analysis suffers an important drawback in terms of its inability to represent the structural response developed in higher modes. In an attempt to contribute to ongoing efforts for developing improved pushover methods, a multi-mode pushover analysis procedure, namely, IRSA (Incremental response Spectrum Analysis) was introduced recently by the second author to enable two- and three dimensional nonlinear analyses of buildings and bridges. The practical version of IRSA works directly with smoothed elastic response spectrum and makes use of the well-known equal displacement rule to scale modal displacement increments at each piecewise linear step. The objective of this paper is to evaluate and verify the effectiveness of IRSA through a set of nonlinear response history analyses. Typical frame structures of five different heights (4, 8, 12, 16 and 20 stories) were designed to Turkish Seismic Code (1998) provisions for three strength levels (R=2, 4 and 6). For nonlinear response history analysis, 20 real records with earthquake magnitude between 6.0 and 7.5 were employed. The records were appropriately scaled to match a smoothed elastic response spectrum that was also used in multi-mode pushover analysis by IRSA. Results are presented in terms typical nonlinear response quantities, such as inter-story drift ratios and plastic hinge rotations. It is shown that for practical purposes IRSA is able to predict the nonlinear response of all types of buildings investigated with reasonable accuracy including high-rises dominated by higher mode effects.

### EVALUATION OF RECENTLY IMPROVED APPROXIMATE NONLINEAR ANALYSIS PROCEDURES – ID 628

*S. Akkar, Middle East Technical University, Turkey*
*A. Metin, Middle East Technical University, Turkey*
*A. Yakut, Middle East Technical University, Turkey*

The ATC-55 project has presented two improved nonlinear procedures for the estimation of maximum deformation demands on structural systems to assess their performance against different seismic hazard levels. The initial versions of these procedures are recommended by the ATC-40 and FEMA-356 documents and the main difference between them is the particular approach used in simulating the nonlinear equivalent single-degree-of-freedom (sdof) system response. This study evaluates these recently improved approximate procedures for moment resisting frames in a statistical manner to investigate their accuracy in estimating the inelastic deformation demands. A total of 78 ground motions recorded on soil sites were used to produce error statistics for 3 to 9 story frame models that confirm to the modern seismic design codes. The magnitude (M) and closest source-to-site distance (d) range of the selected ground motions are $5.7 < M < 7.6$ and $d < 25$ km, respectively. Nonlinear response history analyses were conducted for 24 non-degrading, 3 to 9 story frame models with fundamental periods ranging between 0.27 s – 1.31 s and the results were compared with those of the approximate procedures to evaluate their accuracy. The nonlinear response history analyses results were considered as "exact" . In particular, the study focuses on the discrepancy and accuracy in the estimation of maximum interstory and roof drift demands between these procedures. Confined to the building models and ground-motion data set, the error statistics suggest that both improved procedures tend to yield conservative estimations for roof drift demands. The corresponding estimations draw a more complex pattern for maximum interstory drift demands. These results are believed to be important for performance-based seismic assessment of existing frame type structures.

### DRIFT DEMANDS OF FAULT-NORMAL NEAR-FIELD GROUND MOTIONS FOR MDOF SYSTEMS – ID 179

*Q. Fu, Stanford University, United States*
*C. Menun, Risk Management Solution, Inc, United States*

With the increased emphasis on deformation-based seismic design in the current practice, it is desirable to develop procedures for predicting the structural deformation quantities that control design and performance of multi-degree-of-freedom (MDOF) systems subjected to fault-normal near-field ground motions. Based on the results of an extensive set of linear and nonlinear the time-history analyses performed on models of 3-, 9- and 20-story SMRF structures subjected to 64 fault-normal ground motions, the empirical factors that relate the structural deformations to the first mode elastic spectral displacements are computed and compared to those reported for far-field ground motions by other researchers. It is shown that the simple coefficient-based procedure specified in FEMA 356 to estimate the drift demands in a MDOF system from its elastic first-mode spectral displacement is applicable to fault-normal near-field ground motions provided the coefficients used in the method are modified. In particular, it was found for fault-normal ground motions that the coefficients are dependent on the fundamental elastic periods of the structure relative to the period of the velocity pulse present in the ground motion. The procedure and modification factors offer an express estimation of the maximum roof displacement and the maximum interstory drift for a given the elastic spectral displacement, and will assist the practicing engineers in the conceptual design and in the estimating displacement demands for fault-normal near-field ground motions.

## ES 3a-III: Structural Engineering - Analysis

Thursday 10:45 - 12:15 – Room 22

### ASSESSMENT OF ADAPTIVE PUSHOVER PROCEDURES BY DYNAMIC ANALYSIS – ID 863

*B. Ferracuti, University of Bologna, Italy*
*M. Savoia, University of Bologna, Italy*
*R. Pinho, University of Pavia, Italy*
*R. Francia, University of Bologna, Italy*

Nonlinear dynamic analysis is the most reliable method to describe structural response under seismic action. Nevertheless, such technique can still be a very time-consuming and complex process, inadequate for general design office application. As such, recent years have witnessed an increased focus on the development of design/assessment procedures based on nonlinear static analysis (or pushover analysis). The latter can effectively describe the capacity of the structure under horizontal forces in the nonlinear range with a reduced computational effort with respect to nonlinear dynamic analysis. Different nonlinear static procedures have been proposed in the literature. They can be subdivided in two main categories; non-adaptive (conventional) and adaptive techniques, the main difference consisting in the manner in which load distributions are prescribed over the structure. In conventional procedures, the shape of the distribution is constant during the analysis, whereas in adaptive pushover methods load distribution is evaluated step-by-step. The adaptive procedure is able to take into account progressive structural stiffness degradation, the change of modal characteristic and the period elongation of a structure for increasing values of external action. In the present study, different pushover procedures, applied to the case of reinforced concrete frames, are compared using the fibre finite element code (OpenSees). For non-adaptive analyses, two different force distributions are considered, uniform and proportional to the first modal shape. For adaptive pushover procedures, Force-based (FAP) and Displacement-based (DAP) technique are employed instead. In order to validate these procedures, incremental dynamic analyses (IDA) are carried out using a set of artificial time-histories derived to fit the Eurocode response spectra. Comparison of static against dynamic results, in terms of both capacity curves as well as interstorey drift profiles, leads to the conclusion that displacement-based adaptive pushover features the highest potential to better reproduce results of incremental dynamic analysis.

### SEISMIC PERFORMANCE SENSITIVITY OF A 9-STORY STEEL FRAME TO PLASTIC HINGE MODELING UNCERTAINTIES – ID 657

*D. Vamvatsikos, University of Cyprys, Cyprus*
*M. Fragiadakis, National Technical University of Athens, Greece*

The effects of different beam-column plastic-hinge modeling assumptions on the seismic behavior of steel frames are studied through Incremental Dynamic Analysis (IDA). The well-known 9-story LA9 2D steel frame is used as a testbed by adopting multiple possible moment-rotation relationships for the beam plastic-hinges. These range from simple elastic-perfectly plastic backbones with kinematic hardening to full quadrilinear backbones with pinching hysteresis, including an elastic, a hardening, a negative stiffness and a residual plateau branch, terminating with a final drop to zero strength. The properties considered include, for example, the post-yield hardening ratio, the end-of-hardening rotation, the slope of the descending branch, the residual moment capacity or the ultimate rotation reached. Such parameters are varied systematically throughout the building, generating numerous plausible structural models which differ only in the adopted connection model, some being rather simple and others quite more realistic. The seismic performance of each resulting frame is then evaluated using IDA, i.e., by performing multiple nonlinear time history analyses for a suite of twenty ground motion records appropriately scaled to several intensity levels. By appropriately post-processing the results we can directly estimate the limit-state capacities to obtain a solid basis for comparing the different models. Thus, we are able to evaluate the influence of plastic-hinge modeling assumptions to the seismic performance of the frame and understand the possible errors introduced by the simpler, less realistic models that are often used in practice.

### FORMULATION OF INTEGRATED BEAM-COLUMN-JOINT MODEL FOR SEISMICALLY NON-CONFORMING R.C. FRAME SYSTEMS – ID 716

*U. S R, University of Canterbury, New Zealand*
*S. Pampanin, University of Canterbury, New Zealand*
*A. Carr, University of Canterbury, New Zealand*

In major seismic prone countries, reinforced concrete frame buildings either designed-for-gravity-loads-only or not conforming to current seismic code requirements have attracted serious attention with respect to seismic vulnerability assessment. As observed in recent earthquake events, such buildings have demonstrated significant distress in the joint panel zone regions, leading to incipient joint failure and loss of safety of the structure.

Experimental studies have further confirmed and highlighted peculiar joint failure mechanisms which underscored the complex phenomena of bond and shear due to inadequate anchorage of the longitudinal reinforcements and absence of transverse reinforcement within the joint. Hence proper modelling of the joint behaviour assumes substantial relevance in seismic assessment and retrofit procedures.

The complexity of joint shear behaviour and the associated intricacies in determining the strength and deformation characteristics pose joint modeling as a research challenge. In the past two decades, various approaches have been adopted such as microscopic finite element models, macro-level multi-spring models and further simplified models with a single spring. Most of the existing macro models have, for simplicity, ignored the interaction between shear and bond and have treated their effects independently. On the other hand, the material models representing force-deformation characteristics are supported by experimentally calibrated parameters. However, only a limited number of experimental tests on under-designed beam-column joint subassemblies are available in literature; hence a comprehensive calibration is yet to be established.

In this contribution, considering the dependency of the macro-models on calibrated parameters on one hand and the complexity of finite element-type micro models on the other, an integrated joint model is proposed comprising of fiber based plastic hinges combined with multi-spring shear panel zone being able to interact with each other. The formulation of the integrated model will be presented along with the validation from quasi-static cyclic tests on seismically non-conforming beam-column joint.

### COMPARISON OF DIFFERENT SEISMIC RELIABILITY PROCEDURES OF RC STRUCTURES – ID 641

*P. P. Diotallevi, DISTART - Dep. of Civil Engineering, Italy*
*L. Landi, DISTART - Dep. of Civil Engineering, Italy*
*M. Bianchini, DISTART - Dep. of Civil Engineering, Italy*

This paper presents a comparison between the fully probabilistic approaches to seismic design and assessment of reinforced concrete structures, as the 2000 SAC/FEMA method and the methods based on the Response Surface. A numerical investigations was carried out considering a set of frame structures designed according to Eurocode 8 and characterized by different structural configurations. The structures were studied with a non linear model which is able to represents the principal aspects of the seismic behaviour of RC elements. With regard to the 2000 SAC/FEMA method three common failure mechanisms were considered: joint failure, column shear failure and drift failure. A standard probabilistic seismic hazard analysis was performed using the Cornell's methodology and the attenuation law proposed by Sabetta and Pugliese. The hazard at the site is defined in terms of the spectral accelerations corresponding to periods close to the fundamental periods of the structures. These accelerations are the intensity factors of the recorded accelerograms used for the dynamic response analysis. With regard to the Response Surface Method, the capacity term in the analytical limit state function was calculated using a response surface and the fragility of systems is calculated by SORM analysis, with the empirical limit state function as input. The response surface is used to model the capacity of a structure as a function of a number of variables representing mechanical parameters as well as loading: the capacity is expressed in terms of the intensity of the seismic action involving a state of failure. The two methods are finally compared and evaluated in terms of failure probability and of computational cost. Moreover the correlation between the failure probability and the structural configuration and typology is investigated.

### FINITE ELEMENT SEISMIC ANALYSIS OF GUYED MASTS – ID 1189

*M. Grey, Oxford University, UK*
*M. S. Williams, Oxford University, UK*
*T. Blakeborough, Oxford University, UK*

Guyed masts are a specialized type of structure commonly used in the broadcasting industry to support equipment at substantial heights. The dynamic analysis of these structures under seismic loading is a much understudied field that requires investigation. The complex nature of their analysis arises from the nonlinear force-deflection relationship of the cable supports as well as P-delta effects in the mast. These lead to the structure exhibiting significant nonlinear characteristics even under working load conditions. Full non-linear analysis of guyed masts is rarely performed as it is complex and time consuming. Masts are usually designed by equivalent static methods for wind and ice loading only, with the seismic loadcase often assumed to be less onerous. The validity of this assumption is investigated as part of this research. In this project four existing guyed masts in the UK with heights ranging from 99 to 312m are accurately analysed under various seismic loading conditions using SAP2000 structural analysis software. The research aims to gain an understanding into the distribution and magnitudes of forces developed during typical seismic and design wind events, establish indicators/trends that may aid in guyed mast design, and identify the circumstances in which seismic loading may be the governing loadcase. Investigations into the 'travelling wave' effect and the suitability of a response spectrum analysis are also undertaken. Applicable sections of Eurocode 8 are followed wherever possible. It is shown that when subjected to substantial seismic events with peak ground accelerations in the region of 4m/s2, significant forces can develop in masts that are comparable to those produced during a wind assessment using the patch load

method. The distribution of forces can be appreciably different and any areas with irregular/inconsistent distribution of wind response forces can be vulnerable to seismic loading.

### SIMULATING THE SEISMIC RESPONSE OF ANCIENT COLUMNS INCLUDING GEOMETRICAL AND MATERIAL NONLINEARITY – ID 1427

*A. Sextos, Aristotle University Thessaloniki, Greece*
*K. Pitilakis, Aristotle University Thessaloniki, Greece*
*N. Argyriou, Aristotle University Thessaloniki, Greece*

The dynamic response of ancient Greek columns attracts scientific attention not only on the basis of their specific flexibility, support and joint connections properties, but primarily, due to the force transfer mechanism between the columns parts that is achieved through wooden or steel pins (called 'empolia'). In fact, this construction practice of finite strength that does not exceed the compressive strength of the connected drums is an early version of the capacity design process that is currently used for the seismic protection of structures. Nevertheless, this is a very complex and multi-parametric problem that involves both geometrical and material nonlinearity; relative sliding and rocking of the drums, the role of non-uniform friction and the variation of axial load as well as potential emplolia fracture lead to a coupled and frequency dependent dynamic response under earthquake loading. Within this context, advanced finite element tools are used in order to investigate the above phenomena and couple them in different combinations. From the simulation of a single 2D drum placed on a rigid foundation to the response of 3D real columns laying over elastic foundation, a parametric analysis is performed, examining the validity of the models and comparing the results with other numerical results and existing simplifying or more complex analytical solutions. The examples studied focus on the actual geometry and characteristics of the ancient columns at the acropolis of Lindos – Rhodes. Additional parametric analyses are also performed based on data from other archeological sites in Greece that have been gathered and achieved into an electronic inventory. The results indicate that the overall seismic performance of the particular monuments is indeed satisfactory to very good, yet the relative contribution of the aforementioned physical parameters is strongly case-dependent and cannot be assessed in advance.

## ES 3a-IV: Structural Engineering - Analysis

Thursday 13:30 - 15:00 – Room 22

### EXPLORING THE CONCEPT OF SEISMIC RESILIENCE FOR ACUTE CARE FACILITIES – ID 29

*M. Bruneau, University at Buffalo, United States*
*A. Reinhorn, University at Buffalo, United States*

Seismic resilience has been defined as the ability of a system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance). More specifically, a resilient system is one that shows: 1. Reduced failure probabilities, 2. Reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences, 3. Reduced time to recovery (restoration of a specific system or set of systems to their "normal" level of performance)

For a geographically distributed system designed to provide a standardized service, such as a power grid, or a water distribution network, the physical resilience dimension can be a quantifiable value, such as kilowatts, gallons, or households provided with service. However, for critical systems for which the deliverable is not a simple engineering unit, such as for the case of acute care facilities, the vertical axis is harder to define, not to mention quantify.

This paper presents concepts developed in attempts to quantify the seismic resilience of acute care facilities, focusing on the structural response as well as response of non-structural elements, expressing these components in resilience dimensions. The problem is framed in a broader societal context, from which is formulated a sub-problem that can be addressed and quantified through a coordinated large-scale multidisciplinary earthquake engineering research effort. Non-engineering issues that closely relate to the engineering ones are considered, but focus of the paper in on the engineering tools that can contribute and be integrated into decision support tools, which in turn could be use for the formulation of strategies and policies at a higher level.

### NEW APPROACHES IN ANALYSIS AND DESIGN OF BASE ISOLATED MULTISTORY MULTIFUNCTIONAL BUILDINGS – ID 194

*M. Melkumyan, American University of Armenia, Armenia*
*H. Hovhannisyan, American University of Armenia, Armenia*

During the last 13 years 37 buildings and structures have been designed in Armenia using seismic isolation technologies. The total number of base and roof isolated buildings, which are already constructed, retrofitted or are under construction, has reached to 26. The last applications of seismic isolation took place in design and construction of 10-20-story multifunctional buildings, which include underground floors (garages) and above ground floors for offices, apartments, restaurants, fitness clubs, pools, etc. The recent developments in the field of seismic isolation of multistory buildings are illustrated in the paper by several examples. The original and innovative structural concepts of five residential complexes and of a business center and their designs were developed in 2004-2006. Under different columns of RC frames and different shear walls of these buildings different quantities of seismic isolation rubber bearings are envisaged. The installation of the group of small rubber bearings instead of one big bearing is not a typical approach. From the structural point of view this approach is increasing the seismic stability of the buildings and is leading to a more uniform distribution of the vertical dead loads as well as of additional vertical seismic loads on the rubber bearings. Other advantages of this approach are the following: • small bearings can be installed by hand without using any mechanisms; • easy replacement of small bearings, if necessary, without using any expensive equipment; • easy casting of concrete under the steel plates with anchors and recess rings of small diameter for installation of bearings; • neutralization of rotation of buildings by manipulation of the number of bearings in the seismic isolation plane, etc. All complexes were analyzed using the provisions of the Armenian Seismic Code, as well as using different time histories.

### NUMERICAL CODE FOR SEISMIC ANALYSIS OF STRUCTURES INCORPORATING ENERGY DISSIPATING DEVICES – ID 648

*P. Mata A, Technical University of Catalonia, Spain*
*S. Oller M, Technical University of Catalonia, Spain*
*A. Barbat H, Technical University of Catalonia, Spain*
*R. Boroschek, University of Chile, Chile*

The evaluation of the seismic response of buildings involves numerical difficulties due to the great amount of factors involved. In fact, the strains–stresses relationship becomes nonlinear beyond the yielding point. The configuration changes are another source of non-linearity, increasing the difficulties in numerical simulations. During strong earthquakes many structures can show a highly nonlinear behavior due to material and geometric behaviors. A realistic structural analysis would require taking into account all the sources of non-linearity, among which the energy dissipating capacity of the structures during earthquakes is essential. Additionally, it is well known that energy dissipating devices can reduce the structural damage providing extra protection to the structure.

The dynamic response of structures with energy dissipating devices is studied in this paper. The structure is modeled using the Vu Quoc–Simo formulation for beams, what allow considering geometric effects in the structural response. Shearing is considered allowing the relative rotation between cross-sections and the beam axis. Ma-

terial nolinearity is treated at material point level with appropriated constitutive laws, employing Kachanov´s model for degrading materials and an elastoplastic material with fiber behavior for steel. The simple mixing theory is used to treat composites. The equations of motion and conservation laws are expressed in terms of sectional forces and generalized strains; the linearized problem is solved by using the finite element method. A specific finite element is proposed for modeling the energy dissipating devices. This element is developed based on simple rods with one integration point.

The beam and dissipating elements were implemented in a finite element code. In this paper several tests validating the ability of the model to reproduce the response of precast and cast in place structures subjected to earthquake loading are presented.

### EVALUATION OF THE SEISMIC BEHAVIOR OF PRECAST CONCRETE BUILDINGS WITH ENERGY DISSIPATING DEVICES – ID 652

*P. Mata A, Technical University of Catalonia, Spain*
*S. Oller M, Technical University of Catalonia, Spain*
*A. Barbat H, Technical University of Catalonia, Spain*
*R. Boroschek, University of Chile, Chile*

The use of precast buildings has been increased due to the high quality of the resulting structures and the reductions of the constructing time. The poor performance of some precast structures during past earthquakes and the lack of specific codes have limited their use in seismic zones. Some of their disadvantages are: low structural damping level, P-D effects and low ductility of connecting joints. Therefore, the use of dissipating devices for improving the seismic behavior precast buildings is proposed in this paper, what would allow to control lateral displacements of structures increasing the global damping and the local ductility of connecting joints.

The seismic response of two precast structures equipped with energy dissipators is compared with the case when dissipators are not employed. The first structure is a low damped industrial precast building with weak connecting joints. The second one is a 3D frame typically built in urban areas with moderate seismicity. The structures are modeled using the Vu Quoc–Simo formulation for beams. Each section is meshed in a grid of quadrilaterals, each of them representing a fiber along the beam axis. The material of the fibers has several components with appropriated constitutive laws. The simple mixing theory is used for resulting composite. A special dissipating element is developed for the energy dissipating devices.

The dynamic response of the two structures is predicted. The possibility of improving the seismic behavior by mean of using dissipators is studied. Additionally, specific dissipating devices are designed for improving the ductility of the connecting joints and to increase the global structural strength. The results confirm the improvement of the seismic performance of precast structures with passive control, reducing the P-D effects, increasing the local ductility and the global strength.

### NUMERICAL-EXPERIMENTAL VALIDATION OF A FULL-SCALE PROTOTYPE – ID 860

*A. Palermo, Politecnico di Milano, Italy*
*L. Ferrara, Politecnico di Milano, Italy*

The continuous spreading of precast concrete structures for one-storey industrial buildings, where the lateral load resisting system consists of columns cantilevering from the foundations and connected with hinges to the beams, have raised up the attention of researchers about the seismic performance of these structures especially in severe earthquake hazard areas. The Growth Research Project "Precast Structures EC8", founded by the European Commission and spanning over three years, aimed to investigate the adequacy of the current seismic design codes (EC8), accepted for cast-in-situ reinforced concrete structures, when applied to the design of these precast concrete structures. In this paper, a numerical-experimental validation of a series of pseudo-dynamic and cyclic tests on two full-scale prototypes, carried out at the ELSA Laboratory of the JRC, is presented. The two prototypes mainly differ because of the different orientation of roof elements and beams, parallel and perpendicular, with respect to the applied earthquake loading. The numerical validation of the experimental tests has been carried out adopting lumped plasticity models: while the roof elements, beams and columns are represented with elastic beam elements (cracked and/or uncracked sections), the plastic hinge regions occurring in the columns are modeled with non-linear rotational springs, adopting suitable cyclic hysteresis rules. Moreover, in order to evaluate the role for the global seismic performance of the system, a parametric analysis investigating the influence of the beam-to-column and roof-beam connections, i.e. varying initial stiffness and cyclic behaviour, will be carried out. A set of accelerograms opportunely scaled to match the EC8 design acceleration spectrum will be used for the dynamic time history analyses as a verification of the EC8 force-based design. The numerical results will confirm on one hand the reliability of the design approach pursued and, on the other, the accuracy, versatility and simplicity of the model adopted.

### CONSEQUENCES OF EARTHQUAKE-INDUCED POUNDINGS OF SEISMICALLY ISOLATED BUILDINGS – ID 1975

*P. Polycarpou, University of Cyprus, Cyprus*
*L. Papaloizou, University of Cyprus, Cyprus*
*P. Komodromos, University of Cyprus, Cyprus*

Seismic isolation is achieved by incorporating flexibility at the base of relatively stiff buildings to avoid resonance with the predominant frequencies of earthquakes and reduce the induced floor accelerations and interstory deflections. However, a practical constraint for the utilization of seismic isolation is the sizeable seismic gap that must be ensured around the building to facilitate the expected large relative displacements at the isolation level. Considering that there are often certain restrictions to the size of the provided seismic gap, a reasonable concern is the possibility of poundings of seismically isolated structures with adjacent structures during strong ground motions. Poundings happen mostly due to the large relative displacements at the isolation level and not due to the deformation of the superstructure, as in the case of fixed-supported buildings. This research work investigates how the effectiveness of seismic isolation may be affected by the various design parameters and conditions during poundings with adjacent structures. A large number of simulations of seismically isolated buildings with a variety of characteristics have been conducted under a range of earthquake excitations in order to systematically investigate the influence of certain parameters and conditions on the maximum floor accelerations, interstory deflections and base shear forces during poundings. The numerical simulations and parametric studies demonstrate that poundings may substantially increase floor accelerations, while other modes of deformations may be excited resulting in higher interstory deflections instead of the almost rigid body motion of the superstructure that is aimed with seismic isolation. Understanding the consequences of potential poundings of seismically isolated buildings with adjacent structures is essential in order to rationally take into account the possibility of impact, which realistically cannot always be excluded, due to practical restrictions.

## ES 3a-V: Structural Engineering - Analysis
Thursday 15:30 - 17:00 – Room 22

### STRENGTH REDUCTION FACTORS FOR BUILDING FOUNDATION SYSTEMS CONSIDERING STRUCTURAL DAMAGE – ID 721

*L. E. Perez Rocha, Instituto de Investigaciones Electricas, Mexico*
*J. Aviles Lopez, Intituto Mexicano de Tecnología del Agua, Mexico*

Strength-reduction factor have been extensively studied in the past for firm ground, and even for soft soils considering site effects. Soil-structure interaction has been recently accounted for

by the authors of this work. This factor was investigated for a single elastoplastic structure with a flexible foundation excited by vertically propagating shear waves. The concepts for fixed-base yielding systems were extended to account for soil–structure interaction by using the simplified reference model and a nonlinear replacement oscillator recently proposed by the writers. In this work, a simplified procedure for practical damage analysis of structures considering the soil-structure interaction effects, is used to compute this R$\mu$ factor. To do that, a damage model based on maximum displacement and dissipated energy under monotonic loading is adopted, with the effects of cyclic load reversals being estimated by using a modified Park-Ang index. To simplify the consideration of the soil-structure interaction effects, an equivalent fixed-base oscillator with the same yield strength and energy dissipation capacity as the actual flexible-base structure is applied. Selected numerical results are presented in terms of dimensionless parameters for their general application, using a set of appropriate earthquake motions for ensuring generality of conclusions. The significance of soil-structure interaction in the structural performance is elucidated and the adequacy of the approach proposed is examined.

## SEISMIC ANALYSIS OF STRUCTURES: INFLUENCE OF THE SOIL – ID 933

*L. Lehmann, Inst. of Applied Mechanics, Germany*
*R. Borsutzky, Inst. of Applied Mechanics, Germany*

In this paper, a new numerical methodology for the analysis of wave propagation in infinite domains is presented and applied to the seismic analysis of structures. A numerical simulation of a three-dimensional soil-structure interaction problem is proposed. For the seismic analysis of a building, data recorded during the Kobe earthquake are used as excitation. The coupled model consists of a near-field part mapped via the FEM and a far-field reproduced by a modified SBFEM. By choosing the FEM for the near-field discretisation and the SBFEM as absorbing boundary conditions several advantages of the solution procedure are achieved: the FEM allows the use of non-linear material laws in the near-field, and utilising the SBFEM reduces the spatial dimension by one, while no fundamental solution is needed. As the SBFEM is formulated as exact absorbing boundary condition, it is non-local in time and space. The non-locality in time is the bottleneck for long simulation time analyses of soil-structure interaction problems, and the globality in space for large near-field/far-field interfaces. The art of formulating a suitable boundary condition is to reduce the complexity of the absorbing boundary condition without accepting significant deviations to the exact solution. Hence, two main modifications are introduced in this paper. In order to reduce the costs of calculating the involved convolution integrals, a recursive algorithm is formulated. A storage reduction method is presented as well, which results in a banded, sparse structure. The combined use of the recursive algorithm and the storage reduction procedure reduces the operating expense of the SBFEM significantly. The application of the presented method to seismic analysis of buildings shows that considering soil-structure interaction besides the correct modelling of soil layers is essential.

## MODELLING SOIL-PILE INTERACTION UNDER LATERAL EXCITATIONS – ID 997

*S. Limkatanyu, Prince of Songkla University, Thailand*
*E. Spacone, University of Chieti, Italy*
*K. Kuntiyawichai, Ubonratchathani University, Thailand*

For many years, designers have considered that piles could only support loads applied in line with their central axis. As a result, piles required to carry lateral forces, were installed at a batter. However, it is now realized that the lateral resistance of vertical pile is considerable. Obviously, interactions between the pile and the surrounding soil should to be considered both in the design and analysis of the structural system (superstructure and pile-foundation) subjected to lateral actions. In this paper, a displacement-based frame fiber model with continuous lateral deformable soils is used to represent the pile-foundation of frame buildings. The proposed model is simple, computationally efficient and capable of representing the salient features of the soil-pile interaction. An inelastic finite element analysis is performed to investigate the effects of soil-pile interaction on the response of structural systems. Several model parameters (e.g. pile length, lateral soil stiffness, pile cross-section geometry) are examined. The parametric studies show that the lateral soil stiffness greatly affects the fundamental period of structural system and the position of the plastic hinge in the pile.

## EXAMPLES OF 3D NON-LINEAR SOIL-STRUCTURE INTERACTION AND ITS APPLICATION TO PERFORMANCE BASED DESIGN – ID 1165

*Z. Lubkowski, Arup, UK*
*N. Peiris, Arup, UK*
*M. Willford, Arup, UK*
*X. Duan, Arup, UK*

The paper describes performance-based analysis techniques used by the authors on a number of recent projects for the more realistic assessment of the seismic performance of structures and foundations at relatively soft sites. The soils at such sites are often strained to their strength limit during strong earthquakes, and are sometimes prone to liquefaction.

Conventional methods of design, or of performance assessment, are based upon treating site response, soil-structure interaction, structural response and foundation design separately, the results of one assessment being used as input to the next.

Whilst this might be a valid approach for linear elastic soils, it is fraught with irreconcilable difficulties in soils that are highly non-linear during an earthquake. This is because the strains in the soil beneath and around the foundation are affected both by the free-field site response and by the inertia forces associated with the structural response. In practice it is not possible to find a simple solution by treating the assessment in separate stages, and a high degree of unnecessary conservatism may be have to be introduced.

The methods adopted by the authors use sophisticated non-linear numerical time domain simulations in 3D including all the essential elements of the system (site response, soil-pile-foundation interaction and the structural response) in one model to permit the non-linear interactions to be represented realistically. The paper describes project applications and validation studies to demonstrate that the approach gives realistic assessments. It shows that questions such as 'how does the presence of a piled foundation affect the site response ground motions to be applied to the structure' to be circumvented by modelling the performance of the whole system.

## FINITE ELEMENT RESPONSE SENSITIVITY AND RELIABILITY ANALYSES OF STRUCTURAL AND GEOTECHNICAL SYSTEMS – ID 1215

*M. Barbato, UCSD, United States*
*Q. Gu, UCSD, United States*
*J. Conte, UCSD, United States*

The goal in performance-based earthquake engineering is to design structures able to achieve specified performance objectives at various seismic hazard levels. To achieve this goal, the structural engineer must account during the design process for all pertinent sources of aleatory and epistemic uncertainty. Thus, methods are required for propagating uncertainties from modeling parameters (describing the geometry, material behavior and applied loading) to structural response quantities used in defining structural performance. These methods also need to be seamlessly integrated with deterministic structural analysis methods well-known to the practicing engineers, such as the finite element method. This paper presents recent developments in response sensitivity, probabilistic response and reliability analyses of structural and geotechnical systems as well as their implementation into general-purpose software frameworks for response simulation based on advanced nonlinear finite element methods. Latest advances are highlighted, which bridge important gaps between algorithms for finite element response and response sensitivity analysis based on the Direct Differentiation Method

(DDM). New DDM-based algorithms for accurate and efficient computation of finite element response sensitivities of structural and soil-foundation-structure-interaction systems are presented. The paper will also provide some application examples in which response sensitivity analysis results are used to assess the relative importance of modeling parameters on simulated system response. Examples of probabilistic response (First-Order Second-Moment approximation), time-invariant (First-Order Reliability Method) and time-variant (mean outcrossing rate computation) reliability analyses are presented to illustrate the integrated use of response sensitivity analysis and probabilistic/reliability analysis methods for probabilistic performance assessment. Focus is placed on two types of analyses commonly used in earthquake engineering, namely nonlinear quasi-static push-over analysis and nonlinear response (or time) history analysis.

### SEISMIC SOIL-FOUNDATION-STRUCTURE INTERACTION: BENEFITS AND DETRIMENTS – ID 1598

*M. Preisig, Ecole Polytechnique Fédérale de Lausanne, Switzerland*
*G. Jie, University of California Davis, United States*
*B. Jeremic, University of California Davis, United States*

Current design practice for structures subject to earthquake loading regards dynamic Soil-foundation-Structure Interaction (SFSI) to be beneficial to the behavior of structures. Including the flexibility of the foundation and soil reduces the overall stiffness of a system and therefore reduces peak loads caused by a given ground motion. This might be true in (some) many cases. However, there is the possibility of SFS system going into resonance with the exciting earthquake motions as a result of a shift of the natural frequencies of the SFS-system. This can lead to much larger inertial forces acting on a structure. In that case, the SFSI is not beneficial, but rather Detrimental to the seismic response of the structures (and of the SFS system). In this presentation we present an analysis of beneficial and detrimental effects SFSI can have on seismic response. It will be shown that an interaction between SFS system and the seismic motions plays crucial role in determining if SFSI will be beneficial or detrimental. In other words, SFSI can be both beneficial and detrimental for a particular SFS system, depending on the characteristics of the seismic motions exciting the system.

## ES 3b-I: Structural Engineering - Bridges

Tuesday 13:30 - 15:00 – Room 22

### SEISMIC BEHAVIOUR OF CABLE-STAYED BRIDGES WITH ADDITIONAL PASSIVE DISSIPATION DEVICES: A STATE-OF-THE-ART REVIEW – ID 35

*G. Valdebenito, Universidad Austral de Chile, Chile*
*A. Aparicio, Technical University of Catalonia, Spain*

Bridges are civil works for which is required their structural integrity and accessibility after the occurrence of an earthquake. However, it is known that these systems are very vulnerable, as it has been demonstrated after the occurrence of the earthquake events of San Fernando (1971), Loma Prieta (1989), Northridge (1994), Kobe (1995) and Taiwan (1999). Considering the existent bridges, cable-stayed ones are without a doubt a very important alternative, since they can be used for long-spans being next to suspended bridges the most impressive engineering works. Because of their importance, for span-lengths that exceed 200 m, it is desirable a conservative design, being common to require an elastic or almost elastic structural response for the design earthquake of very low occurrence probability. Hence, requiring an elastic response and additional energy dissipation on the structural elements, it is possible to use passive devices, as lead rubber bearings, friction dampers or fluid viscous dampers for the seismic control. Born for military use, energy dissipation and base isolation devices began their incursion in the civil world quickly, improving the seismic behaviour of constructions and being the new tendencies in seismic protection of bridges of any kind. This paper corresponds to an actualized state-of-the-art review about the seismic behaviour of cable-stayed bridges with the incorporation of additional systems of passive protection. The investigation begins with a review of the seismic response of cable-stayed bridges, recent research results about the seismic behaviour with additional passive devices and the latest investigations with regard to applications of the passive strategy in the new Rion-Antirion Bridge (Greece).

### NUMERICAL AND DESIGN CONSIDERATIONS OF EARTHQUAKE RESISTANT DESIGN OF TWO DANUBE BRIDGES – ID 1420

*L. Kollar, Budapest University of Technology and Economics, Hungary*
*G. Vigh, Budapest University of Technology and Economics, Hungary*
*L. Dunai, Budapest University of Technology and Economics, Hungary*

According to the former Hungarian standard building structures and bridges were not required to design for earthquke effects. Recently, earthquake resistant design was performed for some major projects, because the seismicity of Hungary is higher than it was thought before (the ground acceleration is about 0.1 g) and the new European standard (EC8) is going to be introduced in 2006, which requires the earthquake resistant design.

Our experience on the design of two new bridges – an arch bridge and a cable stayed bridge – are presented, which are under construction now over the River Danube.

The modal response spectrum earthquake analyses (recommended by EC8) of the bridges were carried out, both by FE models and by simplified procedures. In performing the FE calculation with a high number of degree of freedom, numerical problems arose that may lead to confrontation with the rules of EC8. In the calculation of both bridges, in order to reach the 90% of the total mass by the sum of the effective modal masses (as prescribed by EC8), an extremely large number of modal shapes had to be considered in the response spectrum analysis. In addition, only a few of the modes result in a modal mass greater than 5% of the total mass. As a consequence, the EC8 proposal that modes having modal masses over 5% should be considered in the analysis may lead to extremely unconservative results, since these modes give only about 40% of the total mass. The problems originate in two phenomena: unmoved masses and the decomposition of modal shapes, which are explained, and addressed in the paper.

Based on the results, earthquake-sensitive points of the structures are determined and corresponding structural modifications, strengthening are recommended. Finally, general conclusions are drawn on the effects of earthquake loads on Hungarian bridge structures.

### DYNAMIC RESPONSE OF A BRIDGE PIER MODEL AT THE EUROSEIS-TEST SITE INCLUDING SOIL FLEXIBILITY – ID 197

*G. Manos, Aristotle University Thessaloniki, Greece*
*V. Kourtidis, Aristotle University Thessaloniki, Greece*
*A. Sextos, Aristotle University Thessaloniki, Greece*
*P. Renault, RWTH, Germany*
*S. Chiras, Aristotle University Thessaloniki, Greece*
*V. Soulis, Aristotle University Thessaloniki, Greece*

This paper presents results of the measured and predicted response of a bridge pier model structure which has been erected at the Volvi-Greece European Test Site. After an initial laboratory testing of the bridge pier model under cyclic horizontal loads and the study of its cyclic post-elastic behavior, a series of low-to medium intensity excitations were performed at the test site for a period of two years. The deck acceleration response was recorded and was studied in the frequency domain in order to extract the most significant eigen-modes and eigen-frequencies for the various configurations of the pier bridge model. Moreover, an extensive numerical simulation of the response was also performed, including the flexibility of the foundation. The numerical simulation was also

extended to include a volume of soil under the foundation in order to study the soil response when the pier was subjected to low intensity man-made excitations. Four pressure cells were placed in the soil under the foundation and measurements were obtained from these pressure sensors during the man made excitations, which were then correlated to the numerical predictions. A summary of the in-situ measurements of the bridge pier model response are presented and compared with the corresponding numerical predictions from a variety of numerical simulations that attempt either in a relatively simple or a relatively complex way to address the influence on the response that arises from the flexible foundation conditions.

### RESPONSE OF CABLE STAY BRIDGES SUBJECTED TO MULTIPLE SUPPORT EXCITATION – ID 222

*E. Metters, University of Bristol, UK*
*C. Dick, University of Bristol, UK*
*J. Norman, University of Bristol, UK*
*A. Crewe, University of Bristol, UK*

Multiple support excitation during earthquakes is a significant hazard for structures with large distances between ground support points. Typically this applies to long-span bridges, but may also be significant for buildings and other structures with a large plan area, particularly if the geological/soil conditions under the structure are non-uniform.

A significant amount of research has been carried out in the field of multiple support excitation using various numerical models. To date, little experimental testing has been carried out in order to verify the theory and to test the nonlinear behaviour of structures under extreme loading cases.

In this paper we present results for a series of experimental tests on a multi degree of freedom model of a bridge. The model tested is an accurate dynamic model of the Jindo cable stay in South Korea. The actual bridge has a 350m main span and two 70m approach spans. The test model is 1/150th the size of the real bridge and is 3.3m long.

Initial tests using a shaking table were used to establish the behaviour of the bridge under synchronous excitation. The model was then moved onto a set of four single-axis shaking tables which provided variable input motions into each of the bridge supports.

The response of the bridge has been recorded for different time delays between support points. The experimental results are compared with numerical results calculated using finite element analysis and show that in certain cases, when subjected to multiple support excitation, the bridge response can be significantly altered compared to that for purely synchronous excitation.

### INVESTIGATION OF STOCHASTIC SEISMIC RESPONSE OF BASE-ISOLATED BRIDGES UNDER WAVE-PASSAGE EFFECTS – ID 306

*B. Csak, Budapest University of Technology and Economics, Hungary*
*S. Ates, Karadeniz Technical University, Turkey*
*A. Bayraktar, Karadeniz Technical University, Turkey*
*A. A. Dumanoglu, Karadeniz Technical University, Turkey*

Stochastic seismic analysis of an isolated bridge subjected to spatially varying earthquake ground motions is performed. Friction pendulum systems are selected as seismic isolation bearings which are sliding devices that utilize a spherical concave surface. The spatially varying earthquake ground motion is characterized by wave-passage effect. The importance of the wave-passage effect, which arises from the difference in the arrival times of waves at support points of the structure, is investigated particularly. In order to investigate stochastic response of isolated bridges, a two-dimensional analytical model is selected as numerical example. The bridge model is subjected to spatially varying earthquake ground motions in the horizontal direction. The bridge has uniform mass and stiffness properties along its continuous deck with a cross section. The horizontal input is assumed to travel across the bridge from left to right side with finite velocities of 100, 200 and 400 m/s for soft soil type. The acceleration spectral density function for soft soil type is applied to each support points as an earthquake ground motion. The arrival times are taken into account as 0.0 s for all support points when the apparent wave velocity is assumed infinite. This situation corresponds to uniform ground motion. As a result, the deck member forces have the same variations for uniform ground motion and the wave-passage effect when the friction pendulum systems are used for seismic isolation of bridges. The total stochastic response values of the isolated bridge carried out for the spatially varying earthquake ground motions are dominated by dynamic component. The bending moments, shear and axial forces decrease with increasing apparent wave velocities. To generalize the results, solutions must be obtained using many earthquake ground motions and different bridge models. Results obtained from different ground motions and models must be evaluated together.

### ADVANCED SEISMIC ISOLATION SYSTEM FOR BRIDGES BASED ON OPTIMIZED SEISMIC ENERGY BALANCE – ID 360

*D. Ristic, IZIIS, Macedonia*
*V. Micov, IZIIS, Macedonia*
*M. Vucinic, RZUP, Yugoslavia*
*M. Jovanovic, IZIIS, Macedonia*

Development of advanced technology for efficient prevention of heavy earthquake catastrophes in the future was the main and challenging motivation for the first author to start with realization of the present long-term pilot-innovative project entitled: "High Performance Seismic Isolation of Bridges". The new technology for qualitatively improved seismic protection of bridge structures is based on application of patented efficient "GOSEB2" system for construction of seismically safe structures. Qualitative step of GOSEB2 (generation-2) innovative seismically-resistant bridge system, shortly named G2-BR, is created with full global optimization of seismic energy balance. The original confirming research results are obtained from realized extensive experimental and analytical study. The proposed new technology for the first time was promoted at EXPO-2000, the largest world exhibition of inventions and new technologies for the 21st century, held in Hanover, Germany, (June 1 to October 31, 2000). The innovative project was officially nominated by the Government of the Republic of Macedonia to represent new and advanced national achievements in the field of INVENTIONS AND SCIENCE. The research activities are continued in the frame of 3-year bilateral scientific project Macedonia-Serbia and Montenegro (2005-2007) and will be more concentrated to practical application of the invented GOSEB2 System.

## ES 3b-II: Structural Engineering - Bridges

Tuesday 15:30 - 17:00 – Room 22

### ASSESSMENT OF POUNDING FORCES IN SEISMIC RESPONSE OF ISOLATED BOX GIRDER BRIDGES CONSIDERING SOIL-STRUCTURE INTERACTION – ID 592

*A. M. Halabian, Isfahan University of Technology, Iran (Islamic Republic Of)*
*A. Salehi, Isfahan University of Technology, Iran (Islamic Republic Of)*

Extensive damages or even collapses of highway elevated bridges during past severe earthquakes indicated that impact between bridge deck and abutments may have significant effects on dynamic response of these types of structures. In this study, an analytical model is employed to examine various parameters affecting the seismic behavior of isolated box girder bridges and evaluate pounding between deck and abutment considering soil-structure interaction. A finite element method is used to model a continuous three-span box girder bridge using new practical approach developed by authors to determine dynamic stiffnesses of seat type abutment systems. For an extensive parametric study,

some important parameters including soil conditions of pier and abutment foundations, type of foundation, stiffness characteristic of backfill, property of elastomeric bearing and seismic excitation were chosen to represent all practical aspects of the issue in the bridge industry. Three-dimensional nonlinear time history analyses were conducted for better evaluation of seismic pounding between deck and abutments. The results showed that the pounding forces are affected by gap size and the foundation flexibility as well. The SSI effect may change impact behavior by imposing seismic resonance or changing induced forces in piers. The results also showed that the responses in the transverse direction seems have no influence on these pounding forces and pile foundations has beneficial role for limitation of these forces rather than shallow foundations.

### EFFECTIVENESS OF SEMI-ACTIVE CONTROL ON A SEISMIC-EXCITED ISOLATED BRIDGE – ID 725

*T. Y. Lee, National Central University, Taiwan*
*K. Kawashima, Tokyo Institute of Technology, Japan*

The effectiveness of semi-active control methods using variable dampers on reducing the displacement responses of an isolated bridge subjected to near-field ground motions is studied. The semi-active control system with either a variable viscous damper or a magneto-rheological (MR) damper is applied to a five-span viaduct with high-damping-rubber bearings, designed based on Japan Design Specifications of Highway Bridges. Two control algorithms, the LQR optimal control and the sliding mode control, are utilized to command the variable dampers for comparing the control performance. The dynamic behavior of the isolated bridge to extreme earthquakes is highly nonlinear, even under control. Through numerical simulation, the results show that sliding mode control presents more effective performance than LQR control on nonlinear systems. The semi-active control with a variable viscous damper based on the LQR optimal control algorithm is capable of providing more similar performance by the active control while the semi-active control with a MR damper based on the sliding mode control algorithm is capable of providing more similar performance by the active control. However, both semi-active control systems based on the sliding mode control algorithm show better performance than that based on LQR control algorithm.

### BI-DIRECTIONAL QUASI-STATIC AND PSEUDO-DYNAMIC TESTS OF HYBRID DAMAGE-RESISTANT BRIDGE PIERS – ID 794

*A. Palermo, Technical University of Milan, Italy*
*S. Pampanin, University of Canterbury, New Zealand*
*D. Marriott, University of Canterbury, New Zealand*

Based on previous research investigations started with the PRESSS Program (PREcast Seismic Structural Systems) for the seismic design of precast frame and wall systems, innovative solutions for seismic-resistant bridge piers have been recently proposed as alternative to traditional monolithic solutions. The efficiency of jointed ductile hybrid solutions, where the self-centring capacity, provided by unbonded post-tensioned cables, is adequately combined with the dissipation capacity, provided by external or internal dissipators, has recently been proposed by the authors to be extended to bridge piers and systems. As part of a comprehensive experimental campaign for the development of hybrid bridge piers solution, undergoing at the University of Canterbury, preliminary results of a series of quasi-static cyclic and pseudo-dynamic tests under uni-directional and bi-directional loading regime on 1/3 scaled bridge piers with cantilever scheme will be presented. Comparison with the performance of equivalent monolithic ductile solutions will be given in order to emphasize the enhanced performance of the hybrid solutions. Alternative solutions for the implementation of hybrid pier systems are proposed, based on different arrangements of the unbonded post-tensioned tendons (passing through the foundation block) and internal or external yielding longitudinal dissipaters. The experimental results confirmed the expected higher performance of the hybrid bridge pier when compared to the monolithic one: for similar monotonic moment-rotation capacity, re-centering properties and negligible damage were highlighted by the hybrid solution. In addition, validation and further refinement of previously proposed simple and reliable analytical models, based on lumped plasticity approach, will be carried out.

### SEISMIC PROTECTION OF THE GUADALFEO BRIDGE BY VISCOUS DAMPERS – ID 870

*J. Simon-Talero, Torroja Ingeniera, Spain*
*R. M. Merino, Torroja Ingeniera, Spain*
*S. Infanti, FIP Industriale, Italy*

The Guadalfeo bridge is a continuous 5-span deck steel truss bridge 585 m long located in the mountainous region of Grenada on the A-44 Sierra Nevada Highway in Spain. The bridge deck is 24 m wide and measures 10.35 m top-to-bottom. Its girder cross- section comprises 5 main beams: three on the upper level and two at the bottom. The truss inter-nodes distance is 10 m and the diagonals connecting the nodes have circular hollow section (CHS). A 30 cm thick concrete slab lies atop the truss and pier height ranges from 24 to 85m. The structure is located in a region prone to earthquakes and has been designed to withstand seismic actions characterized by a Peak Ground Acceleration of 0.226g. Under these conditions, a conventional bridge bearing system comprising fixed and sliding pot bearings could not prevent very large deck displacements and pier deflections. Therefore, two design alternatives were investigated. The first solution contemplated shock transmission units connecting the deck to the abutments whilst a second alternative comprised viscous dampers at the same locations. The designer opted for the second solution, which accrues optimum control of both deck displacements and seismic loads on piers and foundations. The viscous dampers utilized are characterized by a 3000kN capacity, ±300mm stroke with a 0.15 damping exponent and are installed in group of five units at each abutment. This paper aims to provide a description of design concepts with particular emphasis on the seismic design as well as the full-scale testing activities on viscous dampers performed at FIP Industriale laboratory in Italy.

### THE APPLICATION OF ENHANCED ENERGY DISSIPATION DEVICE SYSTEM ON BRIDGES – ID 984

*W. S. Li, National Science & Technology Center for Disas, Taiwan*
*B. J. Shih, National Sci- & Tech- Center for Disaster, Taiwan*
*S. S. Ke, National Sci- & Tech- Center for Disaster, Taiwan*

Due to the limited space of bridge structure, the linear fluid dampers have to be installed in expansion joints traditionally, where provides limited space. Under this pre-condition, the energy dissipation capability of linear fluid damper depending on the velocity would be restrained and less competitive than over device. To extend the capacity of damper, the leverage device connects damper and superstructure named "enhanced energy dissipation device system" for increasing the input velocity of damper by arm ratio. Through the adjustment of arm ratio, the input velocity of damper will be magnified. Three principal topics are focused on in this paper; first, the theoretical model of the device system; second the bridge model shaking table experiments and numerical simulations of experiment results about fluid damper and enhanced energy dissipation device system; third, the applications of device in aseismic design and retrofitting of existing bridges. Form the results of shaking table experiments, enhanced energy dissipation device system will efficiently reduce not only the relative displacement between the superstructure and the substructure of bridge models, but also the bending moments and shear forces of piers. These results also support a proof of the availability of linear assumption for the dynamic analysis of bridges with enhanced energy dissipation device system. In frequency domain analysis, it is found the close relationship between transmissibility and the response of structure. As consequence, the heavily damped structure systems do show a lot of potential for this application in civil engineering. For the application of device in aseismic design and retrofitting of bridges, the numerical results show the survivability of bridge systems after the attack of strong earthquake would be increased and the device system is appropriate and effective for upgrading the aseismic

capacity of existing isolated or simply supported systems.

### STRUCTURAL IDENTIFICATION OF BRIDGES BASED ON AMBIENT VIBRATION MEASUREMENTS – ID 1263

*C. Karakostas, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*V. Lekidis, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*K. Papadimitriou, Dpt. Mechan. & Industr. Engng., Univ. of Thess, Greece*
*S. Karamanos, Dpt. Mechan. & Industr. Engng., Univ. of Thess, Greece*
*T. Salonikios, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*K. Christodoulou, Dpt.Mechanical & Industrial Eng., Univ.of Thes, Greece*
*T. Makarios, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*I. Sous, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*P. Panetsos, Egnatia Odos S.A., Greece*

The evaluation of the actual dynamic characteristics of civil engineering structures through measurements of their response to various excitations, has been attracting an increasing research effort worldwide in the past years. Several other studies have been devoted in reconciling finite element models with measured time history or modal data. Each method has its own advantages and shortcomings and there are not universally established methodologies for successfully treating the modal identification and model-updating problems. Efficient model updating techniques are necessary, among others, in the process of constructing a theoretical model of a structure for the purpose of predicting its structural damage. A finite element model updating methodology is developed in the present study for monitoring the condition and assessing the integrity of instrumented bridges by utilizing ambient vibration measurements generated by wind and traffic. The model updating methodology is based on the availability of an incomplete set of modal frequencies and modeshape components at the measured locations. The modal estimates are obtained from vibration measurements using modal identification procedures also developed by the research team for the case of unmeasured (e.g. wind and traffic) excitations. The methodology, using real measured acceleration data obtained from traffic load events, is applied to two bridges on Egnatia Highway in Greece, which have been instrumented with structural accelerometer arrays : (a) a 180 m long, four-span bridge of prestressed R/C beams resting on elastomeric bearings at the piers and the abutments and (b) a 170 m long, T-shaped bridge with a curved, prestressed R/C box girder of variable height, monolithically connected to the central pier, and resting on elastomeric bearings at the abutments. The research effort aims at providing suitable tools to the managing authorities of highways for the evaluation of the structural integrity of bridges under their jurisdiction.

## ES 3c-I: Structural Engineering - Concrete

Monday 13:30 - 15:00 – Room 4

### AXIAL LOAD CAPACITY OF R/C COLUMNS WITH VARIOUS REINFORCING DETAILS AND CONCRETE STRENGTH – ID 347

*D. Kato, Niigata Univ., Japan*
*Z. Li, Niigata Univ., Japan*
*T. Yatutuka, Niigata Univ., Japan*
*Y. Nakamura, Niigata Univ., Japan*

OBJECTIVES In order to avoid pancake type collapse of existing old R/C buildings during severe earthquakes, it is necessary to evaluate axial load carrying capacity of existing R/C columns with poor reinforcing details and low concrete strength. Such columns are vulnerable to fail in shear. Objectives of this study are to examine the axial load carrying capacity of R/C columns after shear failure. We paid special attention to confining effects of hoop reinforcement depending on their reinforcing details and concrete strength.

OUTLINE OF TEST For this purpose static loading tests of R/C columns were conducted. Main variables were the details of hoop reinforcement and concrete strength. Confinement of hoop reinforcement to core concrete was one of the most important effects to be discussed so four types of columns with different hoop reinforcement details were tested, i.e. i)welded hoop for good confinement type, ii)hoop with 135 deg hook for normal confinement type, iii)hoop with 90 deg (long anchorage length) hook for medium poor confinement type and iv)hoop with 90 deg hook (short anchorage length) for poor confinement type. Two types of loading methods were applied, i.e. i)centrical axial loading test to examine the basic confining effects of hoop reinforcement and ii)axial loading test under constant lateral drift angle to examine the axial load carrying capacity after earthquakes.

RESULTS AND CONCLUSIONS Results of all specimens were examined based on Mohr-Coulomb criterion defined by cohesive stress and internal friction angle. Confining stress by hoop reinforcement was assumed to be degraded due to damage of reinforcement depending on the details and concrete strength. Finally evaluating method of axial load carrying capacity of existing R/C columns with various reinforcing details and concrete strength was proposed.

### ANALYTICAL STUDY ON ESTIMATED DAMAGE TO REINFORCED CONCRETE COLUMNS IN AN EARTHQUAKE – ID 344

*K. O. Kanemoto, Institute of Technology, Shimizu Corporation, Japan*
*H. Sakata, Tokyo Institute of Technology, Japan*
*A. Wada, Tokyo Institute of Technology, Japan*

This research is focused on the cracks that occur in reinforced concrete columns after an earthquake. Six approximately 1/2 scale specimens were tested. The cross section of the specimens is 320mm x 320mm. Experimental parameters are shear span to depth ratios, axial force, longitudinal and hoop reinforcing bar strength. Using Dr. Ohno's loading apparatus, six specimens were tested under the cyclic shear force. Crack widths and the quantity of expansion in the shear force direction, flexural and shear displacement and story drift angle in the specimens were all measured. Strains in the longitudinal and hoop reinforcing bars were measured by wire strain gauges at selected locations in the specimens. A digital microscope measured all crack widths across the hoop reinforcing bar that occurred in the specimens. The accuracy of the measurement is 1/1000mm. This paper outlines the experiment and presents the results. We define "Crack Index" in order to estimate the damage of reinforced concrete columns and describe the results that explain the damage level for each parameter using the data obtained from the experiment. "Crack Index" shows the extent of crack relatively. Crack widths at the turn of hysteresis and residual crack widths are estimated under various parameters. The following conclusions can be drawn: 1. "Crack Index" can be useful for an index that shows damage level for damaged structural members. 2. The relationship between "Crack Index" and crack widths are influenced by the parameters used.

### DISPLACEMENT CAPACITY ESTIMATION FOR RC COLUMNS. COMPARISON BETWEEN ANALYTICAL AND EXPERIMENTAL RESULTS – ID 1031

*V. Popa, TUCE, Romania*
*D. Cotofana, TUCE, Romania*

In this paper some results of the experimental program developed within the Romanian-Japanese Technical Cooperation Project on the Reduction of Seismic Risk for Buildings and Structures are presented. One objective of this program is to

evaluate the influence of axial force and transversal reinforcement ratio on the ultimate displacement of some reinforced concrete columns. The tested specimens were detailed according to the Romanian practice in different periods. The question is how proper the values obtained using different world-wide evaluation methods fit the results of the experimental testing. The test series included seven specimens having different transversal reinforcement ratios (0.001..0.006), and different level of axial force intensity, (0.2 or 0.4) (calculated taking into account the mean strength of concrete). The longitudinal reinforcement ratio was considered constant, 0.008. Concrete of class C12/15 have been used to simulate the low quality of concrete used in old buildings. Four procedures have been applied to evaluate the displacement capacity as follows: - a procedure proposed by the EC 8, Part 3 (2005) in Annex A concerning the reinforced concrete structures; - a widely used procedure in Romania that estimate the displacement capacity starting from the moment curvature relation by integrating the curvatures over the column height. The procedure resembles the alternative method proposed by EC8, Part 3; -a procedure proposed in the AIJ Design Guidelines for reinforced concrete buildings; a procedure proposed by Moehle and Elwood. The above mentioned procedures offer reliable results given the high degree of uncertainties related to the displacement evaluation of RC members.

### BOND BETWEEN CORRODED BARS AND CONCRETE UNDER CYCLIC LOADING: EXPERIMENTAL TESTS – ID 661

*M. Valente, Politecnico di Milano, Italy*
*A. Castellani, Politecnico di Milano, Italy*

An experimental program, concerning the evaluation of steel-concrete bond in concrete specimen with corroded bars, is in progress at the Politecnico di Milano. The research is conducted to clarify the bond deterioration process and to highlight the main parameters influencing bond of corroded bars in concrete under cyclic loading. The specimens were kept for ten years in a moderately aggressive environment in presence of clorhides. Experimental tests were carried out to study the effects of repeated cyclic loading, of the natural corrosion and of the confinement on steel-concrete bond. The push-pull tests simulate the conditions of a bar in a beam-column joint subjected to seismic loading as one part of the bar is in tension and the other part is in compression. In some tests the steel yielding preceded the bond collapse influencing the results. Different test results with the same loading history may be explained with the different corrosion level of the steel transversal reinforcement and of the longitudinal bar. The different confinement of the transversal reinforcement caused by corrosion influenced steel-concrete bond, above all the peak value, while it didn't affect the frictional resistance, in accordance with previous studies. The effect of corrosion on bond strength of ribbed bars is studied by finite element analyses, modeling different levels of confinement given by transverse steel reinforcement. The numerical analyses reproduce the experimental results of the bond tests. The effect of cycling loading on bond strength is highlighted.

### APPLICATIONS OF STEEL RETROFIT SCHEMES FOR DEFICIENT BUILDINGS IN TURKEY – ID 1030

*R. Ozcelik, METU, Turkey*
*B. Binici, METU, Turkey*

There is an urgent need of developing reliable upgrade methods and retrofit design procedures for deficient buildings in Turkey. This has motivated to investigate different rehabilitation methods at Middle East Technical University for their possible use in typical deficient buildings with low concrete strength and insufficient confining steel reinforcement details. For this purpose, a five-story deficient building frame located in Kocaeli and having three bays in the short direction and four bays in the long direction was analyzed using static pushover and nonlinear time history procedures. Incremental dynamic analysis was conducted on the case study building to establish a relationship between the induced seismic demand (peak ground acceleration) and capacity parameters (interstory drift and plastic rotations) applying Duzce and Kocaeli ground motions. It has been found that the building in consideration can survive these ground motions for a scale factor of about 0.5. A practical retrofit solution was designed for the deficient frame using two different steel brace configurations, namely X-braces and V-braces. A parametric study was conducted by varying brace sections and the results revealed that despite strength and stiffness gain, there was a decrease in the deformability of the building due to large deformations induced at columns and beam-column joints. It was observed that X-braces are more efficient compared to V-braces, since latter ones impose large deformation demands on beams. An alternative hybrid strengthening scheme composed of jacketing plastic hinge regions of the first story columns along with steel braces was found to yield the optimum solution where both strength and deformation capacity of the structure can be enhanced in an economical way.

### STUDY OF VARIATION IN SEISMIC PERFORMANCE EVALUATION OF CONCRETE FRAMES – ID 500

*T. Takeuchi, Kyushu University, Japan*
*Y. Sun, Kyushu University, Japan*
*T. Fukuhara, Kyushu University, Japan*

Since the Capacity Spectrum Method, one of the currently predominant performance-based seismic design methodologies, utilizes nonlinear pushover analysis to determine the seismic performance point of a structure, reliability of the calculated seismic performance results greatly depend upon the accuracy of the nonlinear pushover analysis. This paper discusses the effects of several primary factors involved in the pushover analysis on the calculated seismic performance of concrete frame structures. The factors dealt with in this paper are: 1) the modeling of the structural element, 2) the variation of the axial load in the side columns of a frame, and 3) the P-Delta effect. Analytical investigation was conducted by utilizing a new beam element proposed in this paper. This beam element is a multi-segment element, and it can take into account the effect of dead gravity on the allocation of the yielding region in the beams of a frame. Based on the analytical results on two standard concrete frame structures, the following observations have been made. 1) The use of dumped hinge element couldn't trace the spread of the plastic region in the beams with the increase of the deformation; 2) the variation of the axial load in the side columns depends mainly on the aspect ratio of the frame, and the axial load in compression may be increased to three times of the initial axial load induced by the dead load; and 3) The P-delta effect must be taken into consideration, since it may not only decrease the maximum capacities, but also change the failure mechanism. Furthermore, variation of the calculated performance points was studied. For the two sample frames, it has become clear that the variation in the axial load of the side columns and the P-delta effect may change the calculated results by five to ten percent on average.

## ES 3c-II: Structural Engineering - Concrete

Monday 15:30 - 17:00 – Room 4

### SEISMIC BEHAVIOUR OF RC STRUCTURAL WALLS WITH DEFICIENT LAP SPLICE AND SHEAR REINFORCEMENT – ID 893

*M. Elnady, McMaster University, Canada*
*A. Ghobarah, McMaster University, Canada*

Structural walls in existing buildings designed to pre 1970s codes may have deficient shear reinforcement and lap splice detailing. Lap splices at the bottom of the wall were designed in compression with anchorage length of 24 bar diameter. When the structural wall is subjected to the lateral load during a major seismic event, the lap splice is in the zone of maximum moment and shear and may be subjected to tension. Such design may cause

nonductile behaviour and sudden failure of the wall due to shear or bond slip of the lap splice reinforcement bars. The objective of this study is to simulate existing design of structural walls with deficient shear reinforcement and lap splice detailing to investigate their modes of failure for the cases of flexural or shear dominated behaviours.

An experimental program was conducted to test two-1/3 scale structural walls under combined axial and lateral cyclic loads. One of the walls was subjected to moment to shear ratio of 5 and the second one was subjected to moment to shear ratio of 2.25. It was found that the lap splice is inadequate to develop the yield strength of the spliced bars and is likely to fail prematurely due to bond slip. The failure mode of the wall without lap splice was premature shear failure due to the insufficient horizontal transverse reinforcement. It is concluded that rehabilitation of existing walls with deficient lap splice and shear reinforcement detailing is necessary to improve their performance and safety when subjected to a major seismic event.

## SOME CONSIDERATIONS ON THE SEISMIC BEHAVIOR OF HYBRID FIBRE CONCRETE STRUCTURAL WALLS – ID 1460

*D. Buzzini, IBK-ETHZ, Switzerland*
*A. Dazio, IBK-ETHZ, Switzerland*

Hybrid Fibre Concrete (HFC) is a cementitious composite material with a high-strength mortar matrix reinforced by steel fibres of different dimensions and shapes. HFC is characterized by high strength and smooth and controlled post-peak softening behaviour, both in compression and in tension. Because of these excellent mechanical properties, HFC is an attractive material for use in earthquake-resistant structures; i.e. it is believed that the use of HFC instead of conventional concrete can significantly simplify the construction of plastic hinges zones, improve their serviceability and ensure at least equivalent structural safety. Therefore, an ongoing study at the Swiss Federal Institute of Technology aims at the development of a HFC for the application in earthquake-resistant structures. The goals of this study are to: 1) Develop a stable and reproducible material; 2) Develop constitutive models for its compressive and tensile behaviour; and 3) Develop new structural concepts tailored to the characteristics of the new material, in order to make the use of HFC even more appealing.

In this paper the mechanical properties of HFC are described, the peculiarities of the newly developed HFC structural walls are discussed and the results of quasi-static cyclic tests on three of them are presented. The seismic behaviour of HFC structural walls is then assessed based on the results of the tests and of the relevant numerical simulation. Finally, recommendations for the further development of HFC structural systems are given and areas where further research is needed are identified.

## ESTIMATE OF CRACK OPENING IN RC WALLS DURING AND AFTER AN EARTHQUAKE – ID 1472

*P. Bisch, Séchaud & Metz, France*
*D. Chauvel, EDF SEPTEN, France*
*J. P. Touret, EDF SEPTEN, France*

In the context of problems linked to leaktightness, durability or ability to repair, there is a high interest in estimating the opening of cracks due to earthquakes in RC walls or shells of industrial structures: tanks, confinement shells, etc. This is necessary either to estimate the rate of leakage after earthquake, or to give a basis of design for an eventual liner. There exists formulas in CEB manuals or in Eurocode 2, but, on one hand, these formulas are well calibrated for beams and previous researches have shown that they are not properly calibrated for thick shear or flexural walls, on the other hand, their domain of use is linked to SLS conditions (serviceability) and there is a question mark concerning their applicability in ULS conditions (seismic situation). A review of available previous experimental data has been carried out, which showed that the measuring of a crack opening during a seismic test is not an easy matter, and finally there exists few reliable data which could offer a basis for an accurate analysis of the problem. However, some experiments which were presented in previous conferences (f. i. SAFE) or which have been performed in a recent past have been reanalysed with these new objectives and have given suitable information as concerns a) the maximal crack opening during a seismic event at the design level, b) the permanent remaining crack opening after such a seismic event. The results of this analysis and the comparison with existing formulas will be presented, together with conclusions and recommendations.

## LATERAL LOAD CARRYING CAPACITY OF FRAMED SHEAR WALL SUBJECTED TO MONOTONIC INCREASED LOAD AT HIGH RATE – ID 358

*Y. Matsuoka, Kinki University Technical College, Japan*
*F. Esaki, Fukuoka University, Japan*
*M. Ono, Kinki University, Japan*

The failure mode of framed shear walls (hereafter referred to as "shear wall") is predicted by the calculated values of the lateral load carrying capacity (hereafter referred to as "load capacity") based on the expressions proposed by the results of static loading tests at comparatively slow speed. However, the shear behavior of shear walls is different from that subjected to the lateral load at high speed such as earthquake load. Their load capacity is affected by the loading rate. In order to investigate the effect of loading rate on the failure mode of framed shear walls, it is necessary to make clear the effect of loading rate on the load capacity of shear walls. The aim of this paper is to make clear the effects of loading rate on the load capacity of shear walls. We conducted the lateral loading tests on the 1/4 scale model shear walls. The specimens were subjected to the increased monotonic lateral load . The experimental variables included in the test series were loading rates (1kine, 5kine, 10kine) and failure modes. The flexural yielding failure mode in the first test series and the shear failure mode in the second were planned. The strain of longitudinal reinforcing bars of all specimens reached a yield strain at the maximum lateral load. However, the observed failure mode coincided with the predicted one under the loading rate in the test series. The load capacity of the shear wall subjected to the load at high speed was larger than that at the low speed. The increased factors calculated by the mean strain rate of diagonal compressive concrete of wall panels for the specimens failed in shear and the strain rate of the longitudinal reinforcing bars for the specimens failed in flexural yielding were close to the increased factor of the load capacity.

## DUCTILITY OF SYMMETRICALLY FLANGED SHEAR WALLS – ID 545

*S. B. Yuksel, Selcuk University, Turkey*

When destructive earthquakes happen, brittle failure should not occur at the tunnel form buildings in which both lateral and vertical loads have been assigned to shear walls. Ductility required for the energy dissipation is closely related with the reinforcement detailing of structural walls. Cross-sectional dimensions of shear walls, reinforcement detailing and the location of confined sections are different than those in columns and beams. Therefore, some problems can arise in deriving moment curvature relationships of shear walls. Available computer programs used to obtain the moment-curvature diagrams have limited capacity in modeling reinforced concrete sections for shear walls. For example, the freeware moment curvature program Response2000 (http://www.ecf.utoronto.ca/ bentz/r2k.htm) does not have an option for modeling confined concrete. Accordingly, the moment curvature response of structural walls having confined end regions cannot be predicted by using this program. For this purpose, a computer program named as Waller2002 has been developed which includes the effects of steel strain hardening, confinement of concrete and tension strength of concrete in deriving moment-curvature relationship of shear walls. The aim of this research is to investigate the moment-curvature behavior of symmetrically wide flanged structural walls that are common components of tunnel form buildings. In this study, the effect of boundary reinforcement and the effect of confinement on symmetrically wide flanged structural walls were investigated. Waller2002 computer program was used

to investigate the moment-curvature relationship of wide flanged structural walls of tunnel form buildings. While deriving the moment-curvature relationship of reinforced concrete structural walls, the effects of steel strain hardening, confinement of concrete and tension strength of concrete were also taken into consideration. The results obtained by Waller2002 for two cases where the longitudinal boundary reinforcement is not confined by using transverse reinforcement were compared with the ones obtained by Response2000.

### SEISMIC BEHAVIOUR OF PRECAST COLUMN-TO-FOUNDATION GROUTED SLEEVE CONNECTIONS – ID 163

*P. Riva, University of Bergamo, Italy*
*A. Belleri, University of Brescia, Italy*

The results of a set of experimental tests concerning the cyclic behaviour of prefabricated column-to-foundation connections is presented. The tests allow to compare the response of cast-in-place connections against pocket foundation and grouted sleeve solutions. The results demonstrate that grouted sleeves ensure a ductility similar to the one of cast in situ column-foundation connections and of pocket foundations, although a slightly smaller dissipation capacity is observed. It is found that in grouted sleeves connections the damage is localized at the column base, in the thin grout layer existing between the prefabricated column and the foundation. As a result, very little damage may be observed in the column, allowing an easier post-seismic column repair.

## ES 3d-I: Structural Engineering - Control

Monday 13:30 - 15:00 – Room 21

### DYNAMIC BEHAVIOR OF A 9-STOREY BASE ISOLATED BUILDING ESTIMATED FROM STRONG MOTION RECORDS – ID 871

*T. Kashima, Building Research Institute, Japan*
*Y. Kitagawa, Keio University, Japan*

Building Research Institute (BRI), Japan, is a national institute that is carrying out research and development on building engineering, architecture and urban planning. BRI is operating a strong motion observation network for buildings covering over Japan as one of its research activities. Kushiro Government Office Building is one of a station of the BRI network and is located in Kushiro City, northern Japan. The building has a base isolation system with 64 natural rubber bearings, 56 lead dampers and 32 steel dampers. A number of valuable strong motion records including a record from the 2003 Off-Tokachi Earthquake (M8.0) have been obtained since the building was completed in 2000. The strong earthquake motion record with 0.26G in PGA and 0.37m/s in PGV was acquired from the 2003 Off-Tokachi Earthquake. The non-linear behavior of the surface geology and the base isolation devices was clearly recognized by means of the spectral analyses of the strong motion record from the 2003 Off-Tokachi Earthquake. The performance of the base isolation devices was verified through the non-linear seismic response analysis using a multi-degree-of-freedom system model. The natural frequencies and the damping ratios of the upper structure were estimated from the wave analyses of all strong motion records. The dynamic characteristics depended upon the amplitudes of response. The natural frequency decreased as the maximum displacement of the upper structure increased. In addition, the difference in the natural frequencies between the cases before and after the Off-Tokachi Earthquake was found out. The estimation of the stiffness and the damping ratio was made using a model with the base isolated storey. The result showed good agreement with the equivalent stiffness and the equivalent damping ratio evaluated from the theoretical hysteresis of the base isolation devices in large displacement range.

### TUNED MASS DAMPERS TO CONTROL THE BASE-ISOLATED BENCHMARK BUILDING MODEL – ID 133

*B. Palazzo, University of Salerno, Italy*
*L. Petti, University of Salerno, Italy*
*M. De Iuliis, University of Salerno, Italy*
*S. Sguazzo, University of Salerno, Italy*

Base isolation has been widely considered as an effective strategy to protect structures subject to seismic excitations. However, it has been shown that, in case of seismic excitations with high energy content at low frequencies, i.e. a near-fault event or a seismic wave propagating through alluvial soil, isolation bearings may suffer major deformations. By increasing the isolation layer damping base displacements can be reduced. However, high damping in the isolation layer affects unfavourably the behaviour of the superstructure. Observing that base-isolated (BI) system responses are dominated by the first-modal contribution and that Tuned Mass Damping (TMD) is able to reduce the fundamental vibration mode, a new idea of combining both properties into a unique system (BI&TMD) was proposed and investigated by Palazzo and Petti in 1994. In this paper, a numerical investigation of BI&TMD combined control strategy applied to the base-isolated benchmark structure is presented. The benchmark base-isolated building model has been developed by Nagarajaiah and Narasimhan (2004), to investigate the performance of various passive, semi-active and active control methodologies. The aim is to test in a comparable way the effectiveness of the BI&TMD passive strategy evaluating several seismic performance indexes under selected seismic excitations. Design criteria of the control system based on the transfer function norm relating the seismic input to the isolators drift are carried out. Results show a mean reduction of the seismic response, over all seismic inputs, of 30% in terms of base displacements, and of 10% of superstructure absolute accelerations, highlighting the efficiency of proposed strategy.

### EXPERIMENT AND ANALYSIS OF SLIDING BEARINGS WITH VARIABLE FREQUENCY FOR NEAR-FAULT SEISMIC ISOLATION – ID 183

*L. Y. Lu, National Kaohsiung First Univ. of Sci. & Tech., Taiwan*
*J. Wang, National Kaohsiung First Univ. of Sci. & Tech., Taiwan*
*C. C. Hsu, National Kaohsiung First Univ. of Sci. & Tech., Taiwan*

The seismic isolation using a conventional sliding isolator of a constant isolation frequency, such as friction pendulum system (FPS), has been proved to be a very effective seismic resistance technology. However, recent studies have also revealed that when a conventional isolation system is subjected to a near-fault earthquake, whose waveform usually possesses a long-period velocity pulse, the system may suffer low-frequency resonance that will cause a considerable amplification of the isolator displacement and endangers the isolated structure. In this study, a sliding isolator with variable isolation frequency that is a function of the isolator displacement is proposed. The sliding mechanism of the proposed isolator is similar to a friction pendulum system, but the sliding surface is made of an axially symmetric surface with a variable curvature in radial direction, rather than a spherical surface with a constant curvature. A sixth order polynomial function has been chosen to define the radial curve of the sliding surface, so that the restoring force of the isolator becomes a fifth order polynomial function of the isolator displacement. By properly defining the values of the polynomial coefficients, the restoring force will have a softening segment followed by a hardening segment as the isolator sliding away from its neutral position. The softening and hardening segments aim to reduce, respectively, the structural acceleration and isolator drift. The result of numerical simulation has shown that when subjected to a long-period pulse-like ground motion, the proposed isolator effectively suppresses the isolator drift without increasing the structural acceleration. In this study, the prototypes of the proposed isolators were also fabricated and tested. The test data verified the feasibility of isolation technology using variable frequency isolators, and have also verified that the hysteretic behavior of the isolator is predictable by the theoretical formula.

### HYBRID PASSIVE CONTROL USING BASE ISOLATION SYSTEMS AND DUCTILE CLADDING CONNECTIONS – ID 1467

*D. Tumay, Georgia Institute of Technology, United States*
*B. Goodno, Georgia Institute of Technology, United States*
*C. James, Georgia Institute of Technology, United States*

Reliable seismic damage control can be achieved by base isolation systems and/or passive energy dissipation (PED) devices, such as ductile cladding connections. While either of these approaches alone is capable of reducing seismic response to acceptable levels, it is reasonable to examine whether a combination of these techniques might be more effective in terms of overall performance and cost reduction. In this study, base isolators and ductile cladding connections are used in combination to enhance serviceability and reduce ductility demand in steel structures subjected to moderate and high seismic events. Nonlinear time history analyses of the combination of base isolation systems and ductile cladding connections were carried out using RAM Perform 2D software. 3, 9 and 20 story SAC buildings were analyzed with ground motions that had different frequency content to investigate the effectiveness of the hybrid system. Ductility demand, peak inter-story drift, energy dissipated through ductile cladding connections and the base isolation system were used as an evaluation and design criteria. Results of parametric studies show that the hybrid system is superior, in terms of enhanced serviceability (e.g., reduced peak displacements, accelerations) and reduced seismic demand on the primary structure, to systems with either base isolation or ductile cladding connections used individually, Also, the ductility demands of the base isolators and ductile cladding connections are decreased in the hybrid system in comparison to the use of either system alone.

### APPLICATIONS AND EFFICIENCY OF A SMART ELASTOMERIC ISOLATOR – ID 1511

*J. Zevnik, Faculty of Civil and Geodetic Engineering, IKPIR, Slovenia*
*M. Fischinger, Faculty of Civil and Geodetic Engineering, IKPIR, Slovenia*
*T. Isakovic, Faculty of Civil and Geodetic Engineering, IKPIR, Slovenia*

The typical force-deflection characteristics of high damping rubber isolators express a significant degree of nonlinearity, which causes the shear modulus to be higher at small deflections. Such nonlinearity has the advantage of providing restraint against unwanted movement under low intensity excitation, such as that caused by wind loading of small tremors. However, the disadvantage is that the degree of isolation for equipment within the structure is less at low level earthquakes than that for design level ones. As shown by the analyses described in the first part of this paper the response of secondary oscillators to events only 10 % of the design case can be of comparable magnitude to the design level response. A smart isolator, based on an elastomer able to adjust its shear modulus by means of applying a magnetic field, could overcome this problem. Recently a prototype of such a device has been assembled and tested within the Vast-Image project. The experimental results show the change of stiffness achieved with such a material is about 35 % at low strains and approximately 20 % at high strains. Based on the experimental data a numerical model has been developed and then used to simulate the response of structures equipped with such devices. In the second part of the paper these results are analysed and compared to those obtained for structures isolated with ordinary high damping rubber bearings.

### SEISMIC PERFORMANCE OF ELEVATED LIQUID TANKS ISOLATED BY SLIDING SYSTEMS – ID 1784

*M. K. Shrimali, MNIT JAIPUR, India*

Seismic response of elevated liquid storage tanks is very important; since they have wide applications in industry, nuclear power plants and connected to public life. In past failure of liquid storage tanks has attracted considerable attention of researchers to protect the structures. In conventional technique increased stiffness of structure attracts higher earthquake forces. However, base isolation, which is implanted between the foundation and structure to isolate the structure, reduces the response of the structure by shifting the energy-containing period of the ground motion beyond the fundamental period of the structure. This will reduce the transmission of ground accelerations to the structure, hence reduces the earthquake forces. In this paper, the earthquake response of elevated cylindrical liquid storage tanks isolated by sliding bearings is investigated under recorded earthquakes. The tank liquid is modelled as lumped mass model. The lumped masses considered are known as convective mass, impulsive mass and rigid mass. The convective and impulsive masses are connected to the tank wall by equivalent springs. The stiffness and damping of the convective and impulsive masses are computed using single-degree-of-freedom concept. The mass of the tower structure is lumped equally at top and bottom. The parameters of the tower structure are computed using the spring-mass system. The behaviour of the sliding bearing is modelled as 2-D idealized Coulomb friction coefficient. In order to measure the effectiveness of the isolation systems the response of the isolated tanks is compared with corresponding response of the non-isolated tanks. It is observed that response of the tank isolated by sliding systems reduces significantly. Hence, the sliding system is effective to control the response of the tanks.

## ES 3d-II: Structural Engineering - Control

Tuesday 10:45 - 12:15 – Room 23

### SEISMIC RETROFITTING OF BUILDINGS USING FLUID VISCOUS DAMPERS. CASE STUDY – ID 406

*A. B. Chesca, NCSRR & IMUAU, Romania*
*R. Vacareanu, TUCEB & NCSRR, Romania*
*R. Ghica, NCSRR, Romania*

Buildings retrofitting using classical methods implies some disadvantages for residents/owners due to the constraints imposed by the construction process. In comparison to traditional seismic retrofitting methods, in the case of introducing viscous dampers, the building may be usable during the whole period of the construction process. If viscous dampers are used in the seismic rehabilitation/retrofitting, it is also important to notice the phase delay between maximum inertia generated forces in structure and maximum forces generated in dampers. In the paper it is investigated the possibility of improving the response of a mid-rise RC frame structure using viscous dampers such as to reduce the large displacements expected during a strong earthquake. The analysed building with basement, ground floor and 3 stories dissipates too little energy through plastic deformations in "hinges" (lack of ductility) and it is characterized by a high risk of extended damage in case of incidence of a major earthquake. The preliminary design of seismic retrofitting for the frame building using linear fluid viscous dampers is performed in the paper. Moreover, the influence of damping on the existing structure is studied as well as the relation between spectral and top displacement for the structure in linear and nonlinear analysis using different values for damping ratios and for the corresponding dampers. The characteristics and layout of the dampers necessary to get the target damping ratio are also investigated. In the case study it was revealed that the use of viscous dampers for seismic rehabilitation is efficient for displacement reduction but not as efficient for base shear seismic force reduction if the structure undergoes large inelastic displacements for the code-imposed seismic demand.

### SEISMIC UP-GRADING OF EXISTING STRUCTURES THROUGH THE INTRODUCTION OF EXTERNAL DAMPERS – ID 17

*R. O. Curadelli, UNCU, Argentina*

*L. F. F. Miguel, Universidade Federal do Rio Grande do Sul, Brazil*
*J. D. Riera, Universidade Federal do Rio Grande do Sul, Brazil*

Increasing awareness of the seismic risk as well as new geological and seismological evidence, are leading to higher strength requirements in new buildings and structures throughout the world. Existing constructions, however, tend to remain as they are, i.e., nothing is legally required and very little is done. The consequence of this state of affairs is that in seismic regions of the globe, perhaps up to 80% of all existing buildings and structures are sub-standard, when their seismic reliability is compared with modern code requirements. In this paper the feasibility of up-grading the seismic strength or reliability of structures by introducing external dampers is examined, with emphasis in medium height concrete building structures and one or two-stories high masonry buildings. In the study, dampers similar to prototypes developed at the Laboratory of Structural Dynamics and Reliability (LDEC), UFRGS, Brazil were considered. In previous papers, the authors show that for purposes of seismic retrofitting of frame structures, external energy dissipation systems may be advantageously used. Through a full reliability analysis of typical steel and reinforced concrete frame buildings, it was demonstrated that the introduction of passive dampers results in a mean five-fold reduction of the probability of failure due to seismic excitation. In this contribution, the influence of external dampers on the seismic reliability of low-rise concrete frames and one or two-stories high masonry structures is examined using a similar approach. A substantial decrease of the probability of failure of the structures studied was verified. It is estimated that the seismic retrofitting may be achieved with costs of the order of 20% of the original cost of the structure.

## PERFORMANCE BASED OPTIMAL SEISMIC RETROFITTING OF YIELDING PLANE FRAMES USING ADDED VISCOUS DAMPING – ID 1300

*O. Lavan, State University of New York at Buffalo, United States*
*R. H. Levy, Technion - Israel Institute of Technology, Israel*

This paper first presents a formulation of an optimization problem for the optimal design of added viscous dampers in yielding plane frames. The optimization problem minimizes the total added damping while constraining local performance indices to allowable values under the excitation of a deterministic ensemble of ground motions. The local performance indices are chosen as the maximal inter-story drift of each story and/or the normalized hysteretic energy dissipated at each of the plastic hinges. The gradients of the constraints with respect to the design variables (damping coefficients) are then derived, using optimal control theory, to enable an efficient first order optimization scheme for the solution of the problem. This scheme is first executed for a single "active" record which is carefully chosen out of the original ensemble. The optimal solution attained for this record is used for a time history analysis, along with each of the remaining records within the ensemble separately, to check whether the constraints are violated for these records. If constraints are violated for some of these records, additional records are added to the "active" set one at a time until the constraints for all records are satisfied. The examples show that in the optimum only one or two records, which are effectively tracked by the algorithm, are expected to be active.

Two examples are then presented: a two story single bay frame which is excited by a single record and a ten story three bay frame which is excited by an ensemble of twenty ground motions. These examples reveal a fully stressed characteristic of the optimal solution, namely, in the optimal solution damping is assigned only in stories for which the local performance index has reached the allowable value.

## COMPLIANT LIQUID COLUMN DAMPERS FOR CONTROL OF SEISMICALLY EXCITED SHORT PERIOD STRUCTURES – ID 45

*A. D. Ghosh, Bengal Engineering and Science University, Shibpur, India*
*B. Basu, Trinity College, Dublin, Ireland*

A compliant liquid column damper (CLCD) system is presented for the seismic vibration control of short period structures, for which, the conventional model of the liquid column damper (LCD) is not practically suitable. First, a formulation for the displacement transfer function of a structure, modeled as a viscously damped single-degree-of-freedom (SDOF) system with a single CLCD, is developed. The selection of optimum design parameters of the CLCD is outlined and a numerical study is made to demonstrate the control achieved by the proposed damper system. Next, the paper studies the case of a multiple compliant liquid column damper (MCLCD) system. The transfer function formulation for the response of the SDOF system with attached MCLCD system is presented. The robustness of single and multiple CLCDs is examined and the optimum number of damper units in the MCLCD system is evaluated. Finally, an experimental investigation is carried out into the performance of a single CLCD attached to a SDOF system with a low natural time period, subjected to harmonic excitation. Acceleration time histories of the SDOF system, with and without damper, indicate the effectiveness of the proposed damper system.

## A VELOCITY AND DISPLACEMENT DEPENDENT SEMI-ACTIVE CONTROL ALGORITHM – ID 630

*C. Oliveira, IST, Portugal*
*L. Guerreiro, IST, Portugal*

Seismic protection of bridges involves different types of control with distinct characteristics. Semi-active control is one of the new fields of research in the area. Semi-active devices are controllable passive devices which have the potential to achieve a performance close to active devices using less energy. Following an algorithm, the semi-active device is capable of modifying its dynamic characteristics in order to improve the global system response. The key factor that determines the full application of that potential is the choice of the right control algorithm. This paper presents the research developed in analyzing the effects of a semi-active device which inputs a force depending on velocity and displacement. The force calculation is based on an algorithm that uses a special combination of displacement, velocity and control criteria causing a considerable improvement of the system response. The control algorithm is presented as well as an application example in a system subjected to different seismic actions, including those considered in the Portuguese and Japanese codes. The results obtained are compared with the no control case and using a passive device, demonstrating the significant advantages of this semi-active control algorithm. The model described in this paper can be easily applied in magneto-rheological or variable-orifice devices. Other methods of creating a semi-active device capable of introducing the forces analysed in a real bridge structure are also introduced.

## AN INVESTIGATION TO ENERGY RESPONSE OF SMART ISOLATED STRUCTURES AND CONTROL EFFICIENCY EVALUATION – ID 1232

*Y. Du, Institute of Earthquake Protection and Disaster Mi, China*
*H. Li, Institute of Earthquake Protection and Disaster Mi, China*
*Y. Dang, Institute of Earthquake Protection and Disaster Mi, China*

Optimal control algorithm is one of the most powerful tools, and has been widely used in structural control. However, due to the special feature of the earthquake excitation that it is not known a priori, current realization of optimal control algorithm for structural vibration control in time domain is based on certain approximation, i.e., either by omitting the earthquake excitation, or by using the so called instantaneous optimal control. The first approximation is usually regarded not to be a true optimal control, and the second approximation has been checked by the senior author and the model for calculating the control force is found out to be mathematically contradicting with each other. The writer developed an improved new optimal control algorithm which has been shown to be more advantageous over the existing optimal control algorithms. This paper presents a control mechanism of both passive and smart isolate structures and evaluation of control efficiency on 3 different optimal control algorithms base on

energy response. Equilibrium equations of cumulative energy and qualitative momentary energy transferring relation in passive and smart isolated structures are derived by using analytic methods and the advantage of smart isolation is shown in terms of energy response suppressing. Base on the qualitative investigation of energy transmission, some primary energy responses are selected as performance indices. The energy response properties for passive and smart isolated systems are compared, and the efficiency for 3 different control algorithms is evaluated. At the end of the paper, a real isolated building which was designed by the senior authors is employed as a numerical example to compare the control effects of different algorithms under two different earthquake waves and two different seismic intensities, respectively. The result shows that the control algorithm suggested by the author has the best efficiency for mitigating seismic energy response.

## ES 3e-I: Structural Engineering - Experimental

Tuesday 13:30 - 15:00 – Room 4

### EXPERIMENTAL SEISMIC RESPONSE OF A FULL SCALE REINFORCED CONCRETE WALL BUILDING – ID 201

*M. Panagiotou, University of California San Diego, United States*
*J. I. Restrepo, University of California San Diego, United States*
*R. Englekirk, Englekirk Partners Consulting Structural Engineers, United States*

The objective of this research program is to verify the seismic response of reinforced concrete wall systems designed for lateral forces that are significantly smaller than those currently specified in building codes in United States. Experience in earthquakes has shown that structural walls are an excellent lateral force resisting system. Structural engineers in California have often questioned that the current design lateral forces for structural wall buildings renders this attractive lateral force resisting system largely uneconomical and that significant savings could be made if lateral forces could be reduced, particularly in the foundation and in the lower levels of the walls where heavy congestion is observed. It is interesting that new displacement-based design methodologies indicate that walls could be designed with significantly less amounts of longitudinal reinforcement and still perform satisfactorily by properly controlling interstory drift, and hence displacement sensitive non-structural damage, and by having sufficient lateral deformation capacity to meet the demands in a rare but strong earthquake.

The test will be conducted in the newly commissioned Large High-Performance Outdoor Shake Figure 1 shows a rendering of the structure that will be tested. The structure will be build at full-scale and subjected to historical input ground motions recorded in Southern California that represent demands of earthquakes with 50% and 10% probability of exceedance in 50 years.The results of the test program will be discussed in that paper.

### SHAKING TABLE TESTS ON THIN LIGHTLY REINFORCED H-SHAPED STRUCTURAL WALL – ID 642

*E. Coelho, LNEC, Portugal*
*M. Fischinger, IKPIR, Slovenia*
*A. Campos Costa, LNEC, Portugal*
*M. J. Falcão Silva, LNEC, Portugal*
*P. Kante, IKPIR, Slovenia*

The paper presents an experimental program on a 5 storey structural wall physical model performed in LNEC 3D shaking table, in Lisbon, within the Project ECOLEADER-LIS. The characteristics of the reduced model and the test set-up are described, as well as the analysis of the main experimental results. Furthermore the results of numerical simulations are discussed.

These tests had the main purpose of studying and evaluating the seismic resistance of thin lightly reinforced structural walls representative of the Central Europe. Particular goals have been: (a) To investigate the influence of simultaneous 3D loading conditions. (b) To address walls with T (H) cross-sections. (c) To investigate the free edge of a T (H) shaped walls in compression and different trypes of confinement. (d) To investigate the behaviour of coupled walls and the behaviour of diagonally reinforced coupling beams in thin walls. (e) To calibrate and further develop numerical models.

Inelastic dynamic analysis was performed using Multiple-Vertical-Line-Element-Model (MVLEM), which was extended into 3D and implemented into OpenSees. This macro model proved the ability to simulate and predict the global behavior of the wall as well as the behavior of confined boundary areas and local extensions of longitudinal reinforcement.

Considerable overstrength was observed in the wall with minimum reinforcement. However, its deformation capacity was limited to less than 1% of the height. Relatively thick slab enhanced the strength of thin coupling beams considerably. Consequently, they did not perform as expected in capacity design and high axial forces as well as shear failure were induced into the wall piers. The EC8 confining reinforcement proved to be efficient. Simpler details (i.e. U-shaped stirrups) might be acceptable for low walls (5-storey) and/or in the case of low seismic intensity. Sequence of loading and pre-cracking influenced the response considerably. The influence of bi-axial loading was relatively low.

### SHAKING TABLE TESTS ON RC FRAME BRACED WITH FLUID VISCOUS DAMPERS – ID 650

*R. Antonucci, Università Politecnica delle Marche, Italy*
*F. Balducci, Consorzio CONIER, Italy*
*F. Bartera, CEA, France*
*M. G. Castellano, FIP Industriale spa, Italy*
*T. Chaudat, CEA Laboratoire EMSI, France*

This paper describes shaking table tests carried out on a one-bay, two-storey, full-scale spatial RC frame (4 m x 4 m, 7 m high, 30 t mass) equipped with fluid viscous dampers atop chevron braces. The tests were performed at CEA Saclay (France) on AZALEE shaking table as part of Ecoleader european project. Said tests were conducted to experimentally verify the effectiveness of dissipative braces to retrofit existing RC-framed buildings originally designed without a seismic resistance requirement or a capacity design approach - thus lacking ductility. In Italy and other seismic-prone, middle European and Mediterranean countries, there are thousands of buildings needing retrofits to present seismic standards - where using dissipative bracings seems very promising. Heretofore, very few dissipative brace retrofits have been attempted in this area using hysteretic and viscous-elastic dampers - and none yet, using fluid viscous dampers. The viscous dampers used were highly non-linear. Thus, with very high dissipation capacity even at velocities lower than the maximum design value. Shaking-table tests were conducted at increasing PGA levels - up to 0.41 g. The seismic input was a 20 s accelerogram generated by EC-8 spectrum, C-soil. Various measurements were made to follow both total and localized structure and dampers behaviour. Results demonstrate that viscous dampers can dissipate up to more than 60 % of input energy, strongly reducing the ductility requirements of RC elements. Energy dissipation provided through viscous dampers also guarantees a strong limitation of inter-storey drift which, for PGAs up to 0.2 g are below 0.5 %, i.e.: the damage limitation value given by EC8 for buildings with brittle-material, non-structural elements. Results are also compared to those obtained with tests carried out on the same frame but without braces, as well as on a similar bare frame, evincing the benefits accrued using viscous dampers.

### SHAKING TABLE TESTS ON RC RETROFITTING FRAME WITH FRP – ID 996

*T. Chaudat, CEA, France*
*K. Pilakoutas, Univ. of Sheffield, UK*
*P. Papastergiou, Univ. of Sheffield, UK*
*M. A. Ciupala, Univ. of East London, UK*

This paper present the main test results and describe the experimental work undertaken on FRP seismic strengthening as part of Ecoleader european program.

Shaking table tests were carried out on a one-bay, 2 storey, full-scale spatial RC-frame (4 m x 4 m, 7 m high, 30 t mass) in 2004 at CEA Saclay on AZALEE shaking table. The main objective of the program was to merge the experience and results of the four partners to experimentally test different strengthening strategies and techniques on a seismically under-designed R/C frame structure, in order to develop simple and rational techniques for use in FRP-strengthening of R/C structural elements (i.e, beams, columns and joints) and quantify their effectiveness through design equations.

Two series of tests were performed : • 5 seismic tests from up to 0.4 g on bare frame, • 6 seismic tests from up to 0.4 g and 5 sine sweep tests up to 0.2 g on the retrofitted frame.

The seismic input was a 20-second accelerogram generated by EC-8 spectrum, C-soil. Various measurements were made to obtain information on global and local behavior of the structure. This frame was strengthened with Carbon fibres by Freyssinet company. The principal of the technique was the minimal application of FRP, only on joints and columns aiming to the creation of plastic hinges on the beams for bigger energy dissipation. In addition, two different joint strengthening methods were applied, validating their effectiveness.

Bare frame tests were conducted in order to obtain severe damages. Damages were mainly located in the joints of 1st and 2nd level. Some cracks were also observed in columns and beams. On retrofitted frame, new cracks appeared in columns and plastic hinges in beams. Tearing of FRP in nodes of the 1st level was observed at the end of tests.

### EFFECTIVENESS OF SEISMIC ROCKING ISOLATION OF BRIDGES BASED ON SHAKE TABLE TEST – ID 364

*D. Sakellaraki, Greece*
*K. Kawashima, Tokyo Institute of Technology, Japan*

Rocking response of a spread foundation which supports a bridge results in mitigation of the bridge response, and this is often called as "seismic rocking isolation". It is effective to mitigate the plastic deformation of the columns. This paper presents a shake table test results to show the effectiveness of the seismic rocking isolation.

### RETROFITTING OF MASONRY STRUCTURES WITH G-FRP STRIPS: VALIDATION THROUGH SHAKING TABLE TESTS – ID 1278

*I. Langone, CESI S.p.A., Italy*
*M. Eusebio, CESI S.p.A., Italy*
*F. Venuti, CESI S.p.A., Italy*
*G. Bergamo, CESI S.p.A., Italy*
*A. Prota, University of Naples Federico II, Italy*

Within the framework of project TE.M.P.E.S., focused on the development of innovative techniques for seismic upgrade of historical masonry structures, tests on two tuff masonry model structures have been conducted to evaluate the effects of different criteria and tools for seismic retrofit. Shaking table tests were performed on representative model structures with the 3D MASTER shaking table operating at the structural laboratory of CESI, Seriate, Italy. The two stories tuff masonry tested building was a 1:2 prototype characterized by in-plane dimensions of 2.60m x 2.85m and a total height of 3.20 m. The three-leaf type of masonry is typical of many structures in Europe and in the Mediterranean area. The prototype has been tested at increasing seismic intensity levels (Colfiorito earthquake, 1997) until a significant level of damage was observed. To reproduce the aftershock conditions, the damaged prototype has been then immediately repaired and retested under two recent Italian Earthquakes [Colfiorito, 1997; Calitri 1980] characterized by different energetic and dynamic parameters. The main aim of the seismic repair was to perform a fast and innovative intervention, which should be able to ensure an immediate operation performance level [FEMA 356/2000]. At the scope, the assessment of the structure has been carried out using the recommendations of the Italian guidelines for existing structures [OPCM 3274]; a fast repair intervention, based on the use of Glass Fiber Reinforced Polymer (GFRP) strips, has been designed using the lately issued guidelines of the Italian National Research Council [CNR 200/2004]. Experimental campaigns and numerical analyses have been performed on the prototype (as-built and repaired) and results have been compared for studying the seismic structural behaviour. The obtained numerical and experimental results have been related to the specific rules suggested by the Italian and European Masonry Building Codes [DM 1987/96, EC6] and Seismic Codes [OPCM 3274, EC8].

## ES 3e-II: Structural Engineering - Experimental

Tuesday 15:30 - 17:00 – Room 4

### EXPERIMENTAL INVESTIGATION OF MASSIVE WOODEN WALL PANEL SYSTEMS SUBJECTED TO SEISMIC EXCITATION – ID 490

*B. Dujic, ULFGG, Slovenia*
*V. Hristovski, IZIIS, Macedonia*
*M. Stojmanovska, IZIIS, Macedonia*
*R. Zarnic, ULFGG, Slovenia*

The research reported herein has been carried out within the bilateral Slovenian-Macedonian project titled "Experimental and Numerical Research of Racking Strength of Massive Wooden Wall Panels" supported by the governments from both countries. The main idea of the project was to obtain reliable data on the mechanism of behavior of massive wooden wall panels that will contribute to design and construction of seismic resistant and safe buildings.

Two full-scale models have been assembled and tested on the shaking table at the IZIIS Laboratory, Skopje, Macedonia. The first test specimen consisted of KLH one unit wall elements with length of 244 cm. The second specimen consisted of KLH two unit wall elements with length of 122cm. KLH panels are product of Austrian Company Massiveholz GmbH and represent cross laminated timber consisted of strips of spruce stacked on top of each other and glued together forming large-sized solid cross-laminated boards.

After placing of the specimens on the shaking table, they were loaded with the ballast and ambient and force vibration methods were used in order to measure the mode shapes and frequencies of the models. Following low-level random vibration tests were applied to measure the linear behaviour of the specimens. Afterwards, several acceleration input motions with gradually increasing intensity were applied on the models and after each earthquake excitation, low-level random vibration tests were undertaken in order to monitor the change of the natural frequencies and eventual damages on the models.

Based on the gained test results further research has been directed towards development of mathematical model that will simulate the behavior of this type of structures subjected to seismic loads.

### EXPERIMENTAL RESEARCH OF R.C. ELEMENTS WITH SUBSTANDARD DETAILS – ID 819

*D. Syntzirma, Demokritus University of Thrace, Greece*
*G. Thermou, Demokritus University of Thrace, Greece*
*S. Pantazopoulou, Demokritus University of Thrace, Greece*
*G. Halkitis, Demokritus University of Thrace, Greece*

Existing structures, designed up to an array of earlier versions of seismic codes as these evolved through the last half century, can be generally classed as 'low deformation capacity' systems, i.e. they have limited ability to sustain large inelastic deformation reversals without strength loss. In terms of reinforcement amounts, structural members typically are lacking in properly detailed

transverse reinforcement resulting in limited deformation capacity of the structural members and of the structural system as a whole. Those 'old type' structural members are experimentally explored, through a series of component tests that comprise sixteen (16) specimens modelling reinforced concrete columns with substandard details representative of former construction practices. Columns are cantilevers with a square cross section of 200mm and lap–splices in the critical region. The longitudinal reinforcement consisted of Ø12, S500 bars whereas the transverse reinforcement was composed of smooth steel of nominal diameter Ø6, S220. Specimens were tested in single curvature under constant axial load and cyclic lateral load reversals simulating earthquake effects. Two loading histories were established; the first resembled 'near field' earthquake effects with a significant increase of displacement from cycle to cycle whereas in the second the displacement amplitude was increased gradually. The critical parameters of the experimental series were the ratio of the longitudinal reinforcement, the volumetric ratio of the transverse reinforcement, the lap–splice length and the loading history. As the detailing of the specimens was representative of old or substandard construction closely interacting modes of failure (shear failure after flexural yielding, lap splice failure accompanied by shear or flexural failure, etc.) were developed. It was concluded that the loading history was determinant for the final response and the mode of failure of each structural member. The results of the experimental work are presented thoroughly.

## RESISTANCE OF STRUCTURES WITH CONTRIBUTION OF FIBRE MATERIALS AND SHAPE MEMORY ALLOYS – ID 215

*E. Juhasova, ICA SAS, Slovakia (Slovak Republic)*
*M. Vrabec, ICA SAS, Slovakia (Slovak Republic)*
*M. Juhas, SjF STU, Slovakia (Slovak Republic)*
*V. Kafka, IAM CAS, Czech Republic*

The paper will describe the results of theoretical analysis, static and static-dynamic tests as well as those of shaking table tests of chosen composite systems.

The analysis comprises Investigation of stresses and deformations of composite structures caused by natural and technological dynamic actions. Analysis is also devoted to typical loading processes and their relations to classical and combined structural systems, which could contain elements made from shape memory alloys. Theoretical and experimental analysis of static and dynamic capacity in view of stiffness and strength of alternative materials and structural combinations will be presented. Theoretical and numerical verification of the system efficiency when shape memory alloys and polymers are applied for increasing the dynamic carrying capacity of structures are especially addressed to seismic resistance of prospective systems in case of high seismic actions.

Calculation models and methods, criteria and conditions to be used for implementation of capacity design method for these systems in Europe and especially in conditions of Central Europe will be discussed in the presented paper.

These tests and analyses have as a main purpose the evaluation of the behaviour of new and older structures where is reasonable to apply different composite materials including fibre ones combined either with polymers or with shape memory alloys.

## PSEUDODYNAMIC AND CYCLIC TESTING OF FULL SCALE PROTOTYPES OF PRECAST R/C ONE STOREY BUILDINGS – ID 365

*L. Ferrara, Politecnico di Milano, Italy*
*E. Mola, Politecnico di Milano, Italy*
*P. Negro, ELSA-JRC, Italy*

In this paper, the experimental activity carried out in the framework of the EC-funded research project Precast EC8 is presented. The project, spanning over three and a half years, aims at investigating the adequacy of current EC8 approach, normally accepted for cast-in-situ r/c structures, when applied to the design of precast structures, through a balanced mix of experimental and numerical activity. The paper focuses on the description of a series of pseudodynamic and tests on full-scale prototypes, representative of typical European precast industrial facilities, carried out at the ELSA Laboratory of the Joint Research Centre of the EC in Ispra. The interpretation of the test results will allow a better insight to be gathered both on the global response of such precast industrial facilities to seismic excitation, as furthermore influenced by the presence of cladding panels as well as by the behaviour of connections. The role of the latters has been also investigated with reference to their efficacy in guaranteeing diaphragm behaviour of the roof system. Time histories of global quantities (displacement of the deck, shear force at the control point, forces in the actuators, absorbed energy) were directly available from the test algorithm. Moreover, a pattern for local instrumentation was placed on the structure to 'capture' all the quantities of interest at element and connection level. In the paper, the most meaningful global and local data collected during the tests are discussed with reference to the open issues in the seismic behaviour of precast industrial structures.

## SHAKING TABLE TEST OF SCALED 4 STORY BUILDING OF 3D-PANEL PREFABRICATED SYSTEM – ID 271

*M. Kabir, Amirkabir University, Iran (Islamic Republic Of)*

The current paper presents the results of a shaking table test of a precast shotcrete sandwich panels, so called 3D panels, which is constructed by 3D system without any frame in 4-storey. 3D sandwich wall panels are used in construction of exterior and interior bearing and non-load bearing walls and floors in building of all types of construction. Model of specimen is constructed in scale of prototype down by 2.35 factors. Shaking table test of a scaled model of the building were carried out under seismic motion to verify the safety of the system. Objectives of the study are to obtain seismic performances of the described structural system under dynamic loading, such as linear and non-linear structural characteristics, hysteretic behavior, deformability, stiffness degradation and failure mechanism. By this Shaking table tests structural responses such as the seismic damage mechanics and the seismic capacity, the distribution of seismic forces, the weak points in the structures is evaluated. In linear analysis, the primary frequencies, vibration modes and comparison of the results obtained from the test and numerical analysis are presented. In addition, the lateral deformation, story drift and torsion of system are measured experimentally in time domain. Accelerometers are mounted to measure accelerations in both orthogonal horizontal directions. The model was subjected to some scaled seismic record with gradually increasing amplitude.

## SEISMIC TESTS OF A RC PRECAST BUILDING SYSTEM – ID 245

*L. A. M. Mendes, National Laboratory of Civil Engineering, Portugal*
*E. Coelho, National Laboratory of Civil Engineering, Portugal*
*A. Campos Costa, National Laboratory of Civil Engineering, Portugal*

This paper describes the seismic tests preformed at LNEC in a RC precast structure. The tests were made with the support of the European Commission and in the scope of the research project "PRECAST STRUCTURES EC8 - Seismic Behaviour of Precast Concrete Structures with Respect to Eurocode 8". The reference prototype is a typical Portuguese precast system used mainly for industrial buildings and was designed and constructed by a precast company with their common practice. The structure has 12.0x10.5 m2 in plan and 2 storeys with 4.5 m of height. During the erection, the beams are supported by steel angles or by steel hollow boxes which are part of the beam-column connections. The connections are completed by welding and bolting of reinforced bars and steel plates. The system can be considered as jointed with dry connections of limited ductility. The tests were divided in two phases. At first it was tested a 1:3 scaled specimen in the LNEC's 3D shaking table, adopting the Cauchy-Froude similitude law. The earthquake input was the semi-artificial "Tolmezzo" accelerogram

made compatible with the Eurocode 8 response spectra (soil B and 5% of damping). The structure was subjected to 5 stages with increasing intensity, ranging from PGA=0.07g to 0.95g. It is discussed the observed behaviour, the evolution of the experimental modal frequencies, the floor diaphragm hypothesis, the global displacements, the interstorey drifts and by means of a simplified model, the global forces and the global hysteresis loops. It is also presented the behaviour of 8 beam-column connections which were instrumented with displacement transducers. To study in more detail the behaviour of the connections, a second phase of cyclic tests will be carried out on two types of beam-column connections and on column-foundation connections. The results of these tests can be also presented.

## ES 3e-III: Structural Engineering - Experimental

Wednesday 10:45 - 12:15 – Room 4

### QUASI-STATIC CYCLIC TESTS ON U-SHAPED RC WALLS: TEST DESIGN AND PRELIMINARY RESULTS – ID 1408

*K. Beyer, ROSE School, Italy*
*A. Dazio, ETH Zurich, Switzerland*
*N. Priestley, ROSE School, Italy*

U-shaped or channel-shaped walls are frequently used as lateral strength providing members in RC buildings since their form does not only provide strength and stiffness in any horizontal direction but is also well suited to accommodate lift shafts or stair cases. Although U-shaped walls are very popular in practice experimental results on their behaviour under seismic loading are very sparse and codes do not provide detailed guidelines for their design when a ductile behaviour is aimed for. In this context a test program was developed comprising two U-shaped walls at 1:2 scale with the aim to contribute to the understanding of the behaviour of ductile U-shaped walls under seismic loading. The main difference between the two test specimens is the wall thickness. In this paper the design of the test specimens with emphasis on the shear design is presented. A particular focus is set on sliding shear for which the most common design approaches are compared and discussed. The paper also includes a discussion on the main decisions regarding the test set up. These comprise the design of the load stub which controls warping of the top section and the displacement loading history in bending and torsion. Finally, preliminary results from the first wall are briefly presented.

### EXPERIMENTAL INVESTIGATIONS ON HIGH-PERFORMANCE JOINTED DUCTILE CONNECTIONS FOR PRECAST FRAMES – ID 2038

*S. Pampanin, University of Canterbury, New Zealand*
*A. Amaris, University of Canterbury, New Zealand*
*U. Akguzel, University of Canterbury, New Zealand*
*A. Palermo, Technical University of Milan, Italy*

Recent developments on high performance seismic resisting precast concrete frame systems, based on the use of unbonded post-tensioned tendons with self-centring capabilities in combination, when required, with additional sources of energy dissipation, are herein presented. Alternative arrangements for jointed ductile connections to accommodate different structural or architectural needs have been implemented and validated through quasi-static cyclic tests on a series of exterior beam-column subassemblies under uni- or bi-directional loading regime. The results confirmed the unique flexibility and efficiency of these systems for the development of the next generation of seismic resisting structures, able to undergo high inelastic displacement with limited level of damage and negligible residual displacement when compared to traditional monolithic (cast-in-situ) ductile solutions. In order to further emphasize the enhanced performance of these systems, a comparison with the experimental response and observed damage of 2-D and 3-D monolithic beam-column benchmark specimens designed according to the NZ3101:1995 seismic code provisions is carried out. The reliability and simplicity of recently implemented special code provisions for the design and analysis of jointed ductile systems is also confirmed by satisfactory results of analytical-experimental comparison. In addition, the practical feasibility and efficiency of simple technical solutions to connect precast floor systems and lateral resisting frame systems, without incurring in damage due to displacement incompatibilities are experimentally demonstrated. The reliability of recently implemented special code provisions for the design and analysis of jointed ductile hybrid systems is also confirmed.

### CYCLIC TESTING OF STEEL STORAGE RACKS. BEAM-TO-UPRIGHT AND COLUMN-TO-BASE SUB ASSEMBLAGES. – ID 1152

*J. M. Proenca, Instituto Superior Tecnico, Portugal*
*L. Calado, Instituto Superior Técnico, Portugal*
*C. Castiglioni, Politecnico di Milano, Italy*
*G. Tristao, Escola de Engenharia de Sao Carlos, Brazil*

Despite their comparatively low value, steel storage racks are of great importance for modern industry and commerce and their failure may lead to severe economic losses, as well as civil and penal right liability problems. The work herein presented consists of cyclic tests carried out in beam-to-upright and column-to-base sub assemblages in the Instituto Superior Tecnico, of Lisbon. This testing campaign is a part of the SEISRACKS research programme. These tests were carried out in general accordance with widely known recommendations (such as those of ECCS and ATC) for cyclic testing of connections and sub assemblages. On the course of the beam-to-upright cyclic tests an innovative testing procedure was developed by the authors that addresses the vertical (dead and live) load effects. This innovative procedure consists in a mixed, force and displacement, control loading history which reproduces real demands on frame structures. This loading history leads to an unsymmetrical response of the specimens that allows for a more correct definition of collapse, as well of the governing phenomena. A total of 20 column-to-base were performed, considering different axial loads, different directions (down-aisle and cross-aisle) and different loading histories (positive and negative monotonic or reversed cyclic, ECSS, procedure). A total of 30 beam-to-upright connections were tested, considering different (beam) cross-section (70 and 130 mm height), different vertical load effects, different loading histories (monotonic, positive and negative, ECCS and proprietary). Experimental results are presented in a summarized manner.

### FULL-SCALED TEST OF CONCRETE PILE UNDER SEISMIC LOADING – ID 745

*R. Tuladhar, Saitama University, Japan*
*H. Mutsuyoshi, Saitama University, Japan*
*T. Maki, Saitama University, Japan*

Recent researches have clarified that the response behavior of a structure is highly influenced by the response of both the foundation and the ground as well. Hence, the modern seismic design code recommends the seismic response analysis of the whole structural system including superstructure, foundation and the ground. For the development of seismic response analysis method for the whole structural system, however, it is first imperative to clarify the seismic behavior of pile-soil system. In this study, full-scale static and reversed cyclic lateral loading tests were carried out on concrete piles embedded into the ground. The test piles were hollow precast prestressed concrete piles with outer diameter of 45cm and thickness of 7cm. The length of the test piles were 14m. The experimental observations showed that the soil gap occurs between soil and pile in the face opposite to the loading direction. It further showed that significant degradation in lateral stiffness occurs in pile subjected to cyclic loading compared to the monotonic loading. The experimental data were used as the basis for 3D finite element analysis. In 3D finite element analysis,

soil was modeled as 20-node solid elements. For the modeling of concrete pile, comparison between 3-node fiber-theory based beam element and 20-node solid element were carried out. The study showed that the 20-node solid element for concrete pile can better simulate the actual behavior of pile than the 3-node beam element modeling. Moreover, with proper consideration of interface element between soil and pile surface and the degradation of stiffness in soil due to cyclic loading, three dimensional finite element analyses can simulate the seismic behavior of the concrete pile well.

### WET-MIXED SHOTCRETE USAGE IN LOW-DUCTILE REINFORCED CONCRETE FRAMES – ID 892

*P. Teymur Tuga, Istanbul Technical University, Turkey*
*E. Yuksel, Istanbul Technical University, Turkey*
*S. Pala, Istanbul Technical University, Turkey*
*K. Taskin, Istanbul Technical University, Turkey*
*F. Karadogan, Istanbul Technical University, Turkey*

The existence of many vulnerable reinforced concrete buildings in earthquake prone areas built before the current Turkish earthquake code, presents one of the most serious problems facing Turkey, especially Istanbul today. During 1999 Adapazari Earthquake, buildings had greater damage than expected at that magnitude of an earthquake in the city. Since then researchers have been trying to find cheap and easily applicable strengthening solutions for the reinforced concrete and masonry structures. The experiments carried on, show that infill walls increase the lateral load capacity and the stiffness of the structures. It can be stated that when the necessary precautions are taken, the infill walls can be used to strengthen the building. The aim of the proposed work is to find fast, cheap and adequate earthquake strengthening methods for reinforced concrete structures to a "life safety" state. In this study wet-mixed sprayed concrete is used to form an infill wall within a low ductile reinforced concrete frame. The frames were chosen to represent weak column/strong beam type structures that were very common in Turkey especially for the buildings constructed before the current earthquake code. The specimens had non-seismic details such as large spacing of hoops, no hoop in beam-column connection region and no use of 135° seismic hooks. The experimental work is composed of strengthening of one undamaged and one slightly damaged low ductile reinforced concrete frames by forming an infill wall using wet-mixed sprayed concrete. The walls are connected to the frames through shear studs used at four edges of the infill wall to create strong bond between wall and concrete elements. The results of the experiments show that the lateral load carrying capacity of the infilled frames strengthened using this method are approximately two times that of the bare one.

### APPLICATION OF EXPERIMENTAL SOFTWARE FRAMEWORK FOR HYBRID SIMULATION OF STRUCTURES THROUGH COLLAPSE – ID 1221

*A. Schellenberg, University of California at Berkeley, United States*
*S. Mahin, University of California at Berkeley, United States*

Even though hybrid simulation is a versatile, powerful and economically viable experimental method, it is far less utilized than quasi-static or shaking table testing. One of the main reasons limiting the use of hybrid simulation is the absence of a common framework for its development and deployment; thus, to realize the full potential of hybrid simulation, an environment independent software framework is needed that is robust, transparent, scalable and easily extensible. In order to achieve this desired flexibility, the software framework should be highly modular. Therefore, based on object-oriented software design methodologies, a set of interrelated software classes is described herein, which in their unity form a framework for integrating experimental testing with the object-oriented finite element software OpenSees (Open System for Earthquake Engineering Simulation). OpenSees provides a wide variety of high performance computational features as well as network-based simulation and communication capabilities, making geographically distributed and other advanced forms of hybrid simulations possible.

By utilizing both the object-oriented experimental and finite element software frameworks, geometric nonlinearities, three-dimensional effects, multiple support excitation and soil-structure interaction can be investigated by incorporating them into the analytical model. One of the most advantageous applications to incorporate geometric nonlinearities into the analytical model is in large displacement tests where a structure is tested until collapse. Contrary to shaking table testing, no large physical masses have to be present in the experimental part of a hybrid simulation. Such large masses could severely damage testing equipment once a test specimen collapses. Hence, the gravity loads as well as the resulting geometric nonlinearities are all modeled analytically. In order to demonstrate a hybrid simulation, wherein a structure is tested under large displacement effects until collapse, a simple one-story frame with two unequally ductile columns is used.

## ES 3e-IV: Structural Engineering - Experimental

Wednesday 13:30 - 15:00 – Room 4

### EXPERIMENTAL MONITORING OF OSCILLATIONS OF FLEXIBLE STRUCTURES – ID 1049

*P. Psimoulis, Dept. of Civil Eng., University of Patras, Greece*
*S. Pytharouli, Dept. of Civil Eng., University of Patras, Greece*
*V. Kontogianni, Dept. of Civil Eng., University of Patras, Greece*
*S. Stiros, Dept. of Civil Eng., University of Patras, Greece*

In the last years there has been growing interest for accurate monitoring of oscillations (displacements and spectral characteristics), semis-static movements (for instance wind or temperature induced), as well as for displacement-based anti-seismic modeling of major flexible structures. Modern geodetic instruments, GPS and robotic theodolite (RTS), have been used for this task, and the first results are very promising. However, the tolerance and the limitation of these instruments have not been confirmed on the basis of independent observations. In order to assess the limitation and the accuracy of robotic theodolite and GPS for monitoring semi-static and dynamic movements, we made a large number of experiments using an oscillating system which produced axial, computer-controlled oscillations of known characteristics. A GPS antenna and a reflector were mounted on the oscillating device, the movement of which was recorded by both RTS and GPS. Experiments were limited to linear, sinusoidal oscillations with frequency and amplitude at the range of 0.05 - 4 Hz and $\pm$0.5 - $\pm$3 cm, respectively and to commercial, conventional instruments and simple-to-apply-techniques. Data collected were analyzed on the basis of spectral and statistical techniques, and computed parameters of the recorded movement (oscillation amplitude and frequency) were compared with the pre-determined (real) parameters; a process permitting determination of the accuracy and of the limitations of the two instruments. Our analysis revealed that for common flexible structures (natural frequencies $\leq$1Hz) GPS can accurately record oscillation amplitudes $\geq\pm$1.0-1.5cm, while for more rigid structures (natural frequencies $>$1Hz) accurate results can be obtained for oscillation amplitudes $\geq\pm$2cm. Furthermore, GPS can define accurately oscillation frequencies up to 4 Hz, while RTS can accurately record oscillation amplitudes of $\pm$0.5cm and define oscillation frequencies up to 1Hz.

### IN-SITU ASSESSMENT OF IMPORTANT EXISTING STRUCTURES - IP LESSLOSS/ SUB PROJECT 5 - A PROGRESS REPORT – ID 549

*R. Flesch, arsenal research, Austria*
*S. Lu, arsenal research, Austria*
*M. Eusebio, CESI/ ISM, Italy*
*A. Campos Costa, LNEC, Portugal*

IP LESSLOSS/ SP5 focuses on innovative methods for the assessment of important existing buildings, which must remain

serviceable also during and after an earthquake (structures of vital importance for civil protection, e.g. hospitals, fire stations, power plants, important bridges, schools, assembly halls, etc.). The main idea is to integrate experimental tools into the assessment procedures. A Level III assessment procedure with a detailed 3D structural model updated via measured dynamic properties will be appropriate in most cases. If such investigations are carried out in the pre-earthquake phase, measures for seismic upgrading can be undertaken in due time. In the post-earthquake phase these investigations will support the determination of the remaining safety and serviceability. Further, simplified vulnerability models for the above structures can be elaborated from detailed case studies, which can be used in the context of Level II or Level I approaches. In the first year two main deliverables were elaborated, which mean the background documentation for the planned 'European Manual for in-situ Assessment of the Earthquake Resistance of Important Existing Structures'. In deliverable D20 assessment methods are demonstrated via case studies for existing buildings, bridges and hospitals. Further, the use of modal identification applied to physical models damaged at LNEC shaking table is shown. The above mentioned manual in two versions, a training version and a application version, will be elaborated mainly in the second year. At the end of the project the layout for an European Assessment Code will be available. The most innovative task of LESSLOSS/ SP5 is 'update of vulnerability estimates via monitoring', which was already started in the first year. The LESSLOSS SP5 -Training workshop will be held in Vienna in June 2007 with a duration of 2 days.

## FORCED VIBRATION MEASUREMENTS OF A ONE-FAMILY HOUSE IN MONTHEY, SWITZERLAND – ID 1940

*F. Weber, EMPA, Switzerland*
*O. Huth, EMPA, Switzerland*
*D. Gsell, EMPA, Switzerland*
*G. Feltrin, EMPA, Switzerland*
*P. Lestuzzi, EPFL, Switzerland*
*R. Peruzzi, Kurmann & Cretton SA, Switzerland*
*M. Motavalli, EMPA, Switzerland*

In collaboration with the Laboratory for Applied Computing and Mechanics of EPFL and the bureau d'ingénieurs civils Kurmann & Cretton SA in Monthey, the Structural Engineering Research Laboratory of Empa had the opportunity to take forced vibration measurement on a one-family house in Monthey (VS), Switzerland. The house consists of a basement, a ground floor and a first floor. Two hydraulic cylinders with maximum dynamic force of 32 kN each were mounted on the first floor. A force transducer measured the shaker force. The two hydraulic aggregates were displacement controlled. Besides sinusoidal displacements, the control software allows also driving any desired displacement of the cylinder piston, e.g., band limited random signals. Acceleration sensors distributed on the first floor and accelerometers positioned approximately in the centre of the ground floor and basement as well measured the response of the house. Ambient vibration measurements showed that the first natural frequency was approximately 10 Hz. Based on that, the house was excited by band limited random processes within the frequency range of 5 to 20 Hz with increasing dynamic forces. The goal was to investigate the influence of the excitation intensity on the eigenfrequencies and damping ratios. The tests demonstrated a strong dependency of the eigenfrequencies and damping ratios on the excitation intensity. The reason for that nonlinear behaviour seems to be related to the interaction between structure and soil. An additional test series with sinusoidal shaker forces was performed with the goal to drive the house into resonance and to damage it. However, due to the very strong system damping damage could not be generated.

## REAL-TIME HYBRID EARTHQUAKE SIMULATION OF A STEEL COLUMN IN A 20-STOREY BUILDING – ID 634

*P. Bonnet, Oxford University, UK*
*M. S. Williams, Oxford University, UK*
*T. Blakeborough, Oxford University, UK*
*M. Ojaghi, Oxford University, UK*

The real-time hybrid simulation technique is a promising experimental method for structural dynamics. It is based on the substructuring principle and can be achieved thanks to the improved capabilities of modern-day digital computing and servo-hydraulic dynamic actuation equipment. In this research, the real-time substructure method is used to study the behaviour of a steel column in the bottom two storeys of a 20-storey building structure under the El Centro N-S earthquake input. The columns for the lower storeys are modelled physically and loaded by dynamic actuators. Due to a limited physical capacity in the laboratory, a 40% scale building structure is tested. The rest of the building structure, consisting of the floors, the remaining columns and the cross braces, is modelled numerically and loaded computationally. The numerical substructure is non-linear and the number of degrees of freedom is large compared to most previous real-time hybrid tests. An unconditionally stable scheme of the Newmark family is employed to solve the time integration problem. The two substructures are solved simultaneously in real-time, with the interface conditions rigorously applied using an adaptive delay estimation scheme and a Laguerre forward prediction technique. The paper presents the experimental method and numerical algorithms, followed by results which demonstrate the completion of an effective real-time experiment on the 20-storey structure. The method is then used to simulate the application of a tuned mass-damper (TMD) device to the building structure under the same earthquake loading. The TMD is easily modelled as an additional part of the numerical substructure. The real-time experiment is repeated and significant response reductions are observed as a result of the TMD presence. The results demonstrate that real-time hybrid testing is capable of application to realistic MDOF systems for experimental structural dynamics.

## EQUIVALENT TIME-VARYING STIFFNESS OF BRACED FRAMES USING WAVELET ANALYSIS – ID 955

*J. Goggins, Buro Happold Engineers Ltd., UK*
*B. M. Broderick, Trinity College Dublin, Ireland*
*B. Basu, Trinity College Dublin, Ireland*
*A. Y. Elghazouli, Imperial College London, UK*

The results of a series of shake table tests on full-scale single storey concentrically braced steel frames are analysed to evaluate the stiffness of the frames at different stages of their response. Each frame possessed a pair of 3.3m long diagonal bracing members with hollow or filled rectangular steel sections that experienced alternating tensile yielding and compressive buckling when subjected to earthquake loading. Consequently, the lateral stiffness of the frame varied continuously as the combined resistance of the braces changed. In all, eight frames with a wide range of brace slendernesses were investigated.

A wavelet-based equivalent linearisation technique is employed to determine the temporal equivalent natural frequency of the frames. The equivalence is established by minimising the difference in local response energy for the nonlinear and equivalent linear systems. This allows the time-varying stiffness of a frame to be calculated throughout its response. It is observed that frame stiffness reduces significantly in later stages of the tests due to the extensive yielding and elongation experienced by the brace members.

These observed frame stiffnesses are compared with initial values determined from the elastic properties of the braces and the measured natural frequencies of the test frames, and with equivalent energy and secant stiffness values. The initial frequencies are shown to be closely correlated with the initial lateral deformations of the braces upon installation in the test frame. Agreement between expected and actual stiffness is best during the first strong ground motion stage of the tests. In later stages, response energy is shown to shift to lower frequency bands and frame stiffness is strongly influenced by the residual lateral deformations in the post-bucked brace members.

### EXPERIMENTAL VERIFICATION OF NUMERICAL MODELS FOR EARTHQUAKE-INDUCED POUNDING BETWEEN STRUCTURES – ID 1095

*R. Jankowski, Gdansk University of Technology, Poland*

Interactions between insufficiently separated structures, or their parts, due to the out-of-phase vibrations have been repeatedly observed during major earthquakes. This phenomenon, often referred as the earthquake-induced structural pounding, may lead to considerable damage or can be even the reason of the structure's total collapse. Several numerical models, such as the linear viscoelastic, the non-linear elastic following the Hertz law of contact and the non-linear viscoelastic model, have been adopted to simulate pounding force during impact. Based on a very limited number of experimental results it has been initially indicated that the non-linear viscoelastic model can be somehow considered as the most precise one among them (see [1]). The aim of the present paper is to verify the accuracy of the impact force models mentioned based on the results of more extensive experimental study conducted on a shaking table under real earthquake excitation. The pounding experiment has been performed using models of two steel towers with different natural frequencies. Additional plates made of steel, concrete and timber have been placed at the top of the towers so as to study the influence of impacts between different building materials. Values of the models' parameters, used in the numerical simulations, have been determined by fitting the experimentally obtained response time histories applying the method of the least squares. The results of the study show that the use of the non-linear viscoelastic model of impact force gives the smallest simulation errors in the pounding-involved structural response histories for all tested building materials.

[1] Jankowski R.: Non-linear viscoelastic modelling of earthquake-induced structural pounding. Earthquake Engineering and Structural Dynamics 34 (2005) 595-611

## ES 3f-I: Structural Engineering - Masonry and Timber

Thursday 15:30 - 17:00 – Room 2

### NON LINEAR ANALYSIS OF MIXED MASONRY AND REINFORCED CONCRETE BUILDINGS – ID 927

*S. Cattari, DISEG, University of Genoa, Italy*
*S. Lagomarsino, DISEG, University of Genoa, Italy*

From the early 20th-century the gradual transformation of the theory and constructive techniques led from the masonry buildings predominance to the reinforced concrete's (RC) structures. With reference to Italy, after severe earthquakes (1908 Messina, 1915 Avezzano Italy) some regulations (Royal Italian Decree, 1924) advised the adoption of the confined masonry by RC frames as aseismic structures. Together with structures conceived with a definite role for the earthquake behaviour, the spreading of RC technology caused the birth of mixed solutions starting from existing structures in order to satisfy functional aspects: masonry structures subjected to internal demolishment, column insertions, RC staircases insertions, plan enlargements or raisings by mean of concrete structures. The structural variety is quite wide and the complex set of specific cases eludes the coded schemes: therefore subject of particular interest becomes the vulnerability of this class. The scientific studies on the combined-system structures are almost absent because of the previously mentioned structural variety, but also because of the problems concerning the mutual interactions. Also the recent codes, both international (EC8 2004) and national (OPCM 3431/2005), provide only brief explanations. Moreover, although there is a well-established background focused on the non linear analysis of masonry structures and RC frames, the set of numerical and experimental instruments for the study of the interaction effects is limited. In this paper, in the masonry's idealisation as equivalent 3D frame (Galasco et al. , 2004), a formulation and implementation of non linear elements is proposed in order to model RC columns, beams and walls. The adopted approach idealises the behaviour as elastic-perfectly plastic with limited resistance and plasticity concentrated at the end-element; the considered failure's mechanisms are as follows: shear and axial stress as weak failure and axial-bending as ductile failure. Some examples show the efficiency of this method and highlight the behaviour's peculiarity of these structures.

### VULNERABILITY OF MASONRY WALLS ROCKING UNDER SEISMIC ACTION – ID 1455

*G. De Felice, University Roma Tre - Department of Structures, Italy*
*I. Carbone, University Roma Tre - Department of Structures, Italy*

The rocking behaviour of a rigid block under seismic action received a particular attention in the recent past. On the one hand, a simplified linearized procedure which makes use of the concept of substitute structure in the context of displacement-based seismic design has been proposed [1]; on the other hand, the validity of such a simple approximate design philosophy has been questioned and the conclusion that rocking structures cannot be replaced by equivalent single-degree-of-freedom oscillators has been attained [2].

The present paper wishes to give a contribution to this discussion, focusing the behaviour of unreinforced masonry walls subjected to out-of-plane seismic action in a probabilistic framework.

In a first step, the wall is represented by a single rigid block; its behaviour under horizontal recorded ground motion is investigated and the seismic demand, measured by the maximum rotation exhibited during the time history, is recorded.

Then, the behaviour of more complex walls, made by several rigid blocks arranged together with different textures, is investigated by using distinct element method and the decay of seismic capacity, represented by the maximum sustainable rotation, with progressive lack of interlocking blocks is investigated.

Finally, using a probabilistic approach, a method for out-of-plane seismic fragility evaluation is proposed, which is based on the estimate of the probability that the demand, as defined above, will overcome the corresponding capacity, depending on the structural and geometrical properties of the wall.

[1] Doherty, K., Griffith, M.C., Lam, N. and Wilson, J. (2002) Displacement based seismic analysis for out-of-plane bending of unreinforced masonry walls, Earthquake Engineering & Structural Dynamics, 31, pp. 833-850. [2] Makris, N., and Konstantinidis, D. (2003) The rocking spectrum and the limitations of pratical design methodologies, Earthquake Engineering & Structural Dynamics, 32, pp. 265-289.

### SEISMIC VULNERABILITY STUDY OF TRADITIONAL HOUSES IN IRAN – ID 680

*M. A. Ghannad, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Bakhshi, Sharif University of Technology, Iran (Islamic Republic Of)*
*S. E. Mousavi Eshkiki, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Khosravifar, Sharif University of Technology, Iran (Islamic Republic Of)*
*Y. Bozorgnia, PEER Center, United States*
*A. A. Taheri Behbahani, Iran (Islamic Republic Of)*

More than 20 million of rural populations of Iran live in 4 million houses which have no lateral load bearing elements and are vulnerable to earthquake. On the other hand Iran is located on Alpine-Himaliyan earthquake belt and has experienced many catastrophic earthquakes in the past some of which are Tabas earthquake 1978 (18,000 deaths), Manjil earthquake 1990 (40,000 deaths), Bam earthquake 2003 (40,000 deaths) and Dahoeieh-Zarand earthquake 2005 (650 deaths). Most of the casualties took place in the rural regions showing the necessity of investigation of retrofitting methods for these houses.

In response to this need a project was defined at Sharif University of Technology under the title "Seismic vulnerability

study of rural houses in Iran". The first phase of this research deals with gathering structural information and classification of rural houses based on their seismic behavior. This paper intends to define the problem by presenting typical rural houses of Iran and a summary of information on their existing situation according to the group's field investigation to eight provinces of Iran. Then the results of some tests on mechanical propertied of adobes are shown and finally elastic modeling of two of the presented typical houses are discussed. Adobe house with dome roof and brick house with arched barrel roof are the two models which their failure mechanisms' are compared with those of the real damaged houses inspected after the earthquake of Dahoeieh-Zarand (2005).

### EXPERIMENTAL INVESTIGATION ON THE SEISMIC BEHAVIOUR OF MASONRY HOUSING IN LOW SEISMICITY AREAS – ID 220

*H. Degée, Université de Liège, Belgium*
*A. Plumier, Université de Liège, Belgium*

The eastern part of Belgium is a typical region of low seismicity, with an evaluated design PGA of 0.1G at the bedrock. Layout of the walls and standard constructional details of simple non engineered constructions in this area do not account for the possibility of such a seismic event and can therefore be really unsafe. In case of an earthquake, dangerous partial collapse (fall of walls, opening of cracks), and even total collapse could occur. Many of these damages have indeed been observed during the earthquake in Liège in 1983 (Magnitude 5.0). It comes then that architects have usually the choice between two main options: either to design without accounting for possible earthquakes, and therefore produce unsafe structures, or to realise specific reinforcements, classical in high seismicity areas, but excessive and uneconomic in North-European countries. This contribution presents the results of an experimental investigation carried out on the shaking table of the National Laboratory of Civil Engineering of Lisbon (LNEC), in order to validate the efficiency of some constructive proposals aiming at improving the structural behaviour of non engineered masonry housing subjected to low to moderate seismic action, with rather low costs. Two specimens have been tested. These specimens were two full-scale small houses with two levels. The first one was built as a traditional Belgian house, while the second included some anti-seismic technical details. The main conclusions are that both specimens were still standing at the maximum earthquake level foreseen for Belgium, but that the improved model was much less damaged regarding crack openings in the walls. Therefore the economic consequences and repair costs would be much lower with these improvements. However the maximum ground acceleration that can be sustained by the structures seems to be very little influenced by the constructional detailing.

### FLEXIBLE JOINT METHOD (FJM) - A NEW APPROACH TO PROTECTION AND REPAIR OF CRACKED MASONRY – ID 282

*A. Kwiecien, Cracow University of Technology, Poland*
*B. Zajac, Cracow University of Technology, Poland*
*P. Stecz, Cracow University of Technology, Poland*
*J. Kubica, Silesian University of Technology, Poland*

Unreinforced masonry (URM) buildings are sensitive to seismic excitation because of their brittle material properties with low tensile strength and massiveness as well. These buildings exhibit little ductility when subjected to seismic loading. Failure in masonry takes place when the principal tensile stresses, developed in the wall under a combination of vertical and horizontal loads, exceed the tensile strength of masonry materials. Cracked buildings function in a new stress state of static equilibrium that is a consequence of post damage redistribution of internal forces. In most cases strengthening of cracked buildings is typically accompanied by stiffening. In certain cases "softening" can be better than strengthening. This point of view based on "softening" presents the Flexible Joint Method (FJM) proposed in the paper, dedicated to structural repairing of cracked masonry structures in seismic areas. In the FJM special polymer fills in cracks of the damaged buildings and thus introduces new strength in place of cracks and causes dissipation of additional input energy absorbed by the new constructed joint. As the result of application of flexible joints between structural elements or in cracks of the damaged building, a bearing structure is obtained of a capacity similar to the primary one, but of greater flexibility and ductility. The masonry structure retrofitted in such a way absorbs better the energy deriving from vibration and does not undergo further destruction in case of dynamic actions. Due to it, in the case of successive shocks the building can carry additional loads at reduced internal forces without suffering from additional damage. Presented method is registered in the Polish Patent Department under No. P-368173. Beside the description of the FJM, results of shear laboratory tests of brick masonry wallets before damage and after repair by use of the FJM are presented.

### INFLUENCE OF THE FRICTION COEFFICIENT ON THE SEISMIC BEHAVIOR OF INCA STONE MASONRY – ID 709

*J. Ogawa, Akita Prefectural University, Japan*
*C. Cuadra, Akita Prefectural University, Japan*
*K. Tokeshi, Akita Prefectural University, Japan*
*H. Kanno, Akita Prefectural University, Japan*
*M. Karkee, Akita Prefectural University, Japan*
*J. Rojas, National University of Cusco, Peru*

One notable characteristic of the Inca stone masonry is that the finely carved stone blocks were fitted without any kind of mortar. However, most of these historical monuments are located in the west side of South America, which is highly seismic zone. The understanding of the dynamic behavior of this type of masonry is important for its preservation. The shapes of the blocks, as well as, the frictional forces generated between these stone blocks without mortar, would generate a particular mechanism against lateral forces from earthquakes. This research attempts to explain some of the mechanisms of Inca stone construction through experiments on roughness and on friction coefficient of stone blocks. In-situ measurements of the roughness and experimental measurements of the friction coefficients were conducted. A series of shaking table test on small scale simple model of stone blocks or bricks were performed. Likewise, a mathematical model was developed to estimate the dynamic behavior of simple stone bricks under seismic loads. The theoretical model takes into account the friction forces, as well as, the possible impact forces between stone bricks during shaking. According to the results from mathematical model, a uniform friction would be appropriate to reduce the possible impact forces. However, a high dispersion of the value of roughness (friction coefficient) for the same brick was obtained from experiments.

## ES 3f-II: Structural Engineering - Masonry and Timber

Friday 13:30 - 15:00 – Room 2

### AN APPLICATION OF THE DIRECT DISPLACEMENT BASED DESIGN TO GLULAM TIMBER PORTAL FRAME-STRUCTURES – ID 932

*D. Zonta, University of Trento, Italy*
*M. Piazza, University of Trento, Italy*
*P. Zanon, University of Trento, Italy*
*G. Giuliani, University of Trento, Italy*

Although a lot of effort has been put in the last years in developing a Displacement Based Design (DBD) methodology for timber structures, most of the works found in literature refer to wood shear-wall buildings. In the same way, seismic codes, as applied to timber, seem to acknowledge the practical design rules derived from these experiments. These findings, however, hardly

extend to those structures, such as warehouses or commercial buildings, based on glued laminated timber portal frames. Indeed, in this case, type, position and performance of the connections are the main features affecting the seismic behavior of the whole building. The work presented in this paper aims at defining a Direct DBD methodology that specifically applies to this family of buildings. The case study investigated is an industrial wood-framed warehouse made of two-hinged frames where the post-beam connections are semi-rigid moment-resisting joints using dowel-type fasteners. The performance of the structure was extensively investigated through numerical simulations using non-linear pushover analysis. The results show that the displacement capacity of the building mainly depends on single joint behavior and only to a smaller extent on the size of structural members. Therefore, an accurate definition of the connection characteristics is essential for predicting the seismic performance of the entire building. These observations allow to define a practical expression for calculating target displacement in a quite simple and reliable fashion. On the other hand, the simulations show that the design base shear is very sensitive to the dissipation capacity of the joints, which is a quite uncertain quantity difficult to predict at the outset. It is therefore clear that in order to apply a DBD methodology, the relationship between ductility and equivalent viscous damping needs to be more deeply investigated via laboratory experiments.

### EXPERIMENTAL INVESTIGATIONS ON LVL SEISMIC RESISTANT WALL AND FRAME SUBASSEMBLIES – ID 983

*A. Palermo, Technical University of Milan, Italy*
*S. Pampanin, University of Canterbury, New Zealand*
*A. Buchanan, University of Canterbury, New Zealand*

The recent development of laminated veneer lumber (LVL) as an alternative to solid timber or glue laminated timber has greatly improved the viability of structural timber for the seismic design of certain buildings. The low mass, flexibility of design and rapidity of construction all create the potential for increased use of LVL timber in low-rise multi-storey buildings in seismic prone areas. Moreover, as recently proposed by the authors, the innovative jointed ductile dry connections and in particular the hybrid solutions, developed during the PRESSS program (Precast Structural Seismic Systems) for precast concrete buildings, can be easily extended to the LVL multi-storey systems. These alternative connections consist of a critical contact section where the rocking occurs, with unbonded post-tensioned tendons and external and/or internal dissipators passing through. The paper presents preliminary results from an extensive experimental test programme in progress at the Structural Laboratory at the University of Canterbury. Preliminary results from a comprehensive experimental campaign are herein presented and critically discussed with reference to beam-column joint subassemblies and wall-to-foundation connections. Quasi-static and/or pseudo-dynamic tests under uni-directional loading regime were performed depending on the specimen type. The proposed innovative jointed ductile solutions consistently showed remarkable seismic performance: no damage in the structural elements, high self-centering capacity, i.e. negligible residual displacements/drifts, provided by unbonded post-tensioned tendons and finally good dissipation capacity provided by the external or internal dissipation devices, the only sacrificial element of the connections.

### SOFIE PROJECT - TEST RESULTS ON THE LATERAL RESISTANCE OF CROSS-LAMINATED WOODEN PANELS – ID 1912

*A. Ceccotti, CNR-IVALSA, Italy*
*M. Follesa, CNR-IVALSA, Italy*
*M. P. Lauriola, CNR-IVALSA, Italy*
*C. Sandhaas, CNR-IVALSA, Italy*

The SOFIE Project is a cooperative research project patronised by the Trento Province, Italy and coordinated and conducted by the CNR-IVALSA (Italian NRC – Trees and Timber Institute).

The main purpose of this project is to analyse a multi-storey building built with cross-laminated wooden panels considering every single aspect of the building behaviour such as static, fire, acoustic, thermal and, particularly, seismic performance.

Buildings made of cross-laminated wooden panels are gaining a broader acceptance even in seismic prone zones like the majority of the Italian territory. However, in Eurocode 8, the European seismic code for earthquake resistance of buildings, no recommendations are given regarding this constructive system. Neither for construction details nor for the seismic behaviour factor to be used in seismic design of this new typology of wooden buildings any information can be found.

In this paper, results from tests on the lateral resistance of cross-laminated wooden panels are presented. Four different configurations of wall panels have been investigated by means of ramp and cyclic displacement schedules taking into account the influence of the anchoring system, the opening layout and the inter-storey connection.

All the tests performed confirmed that the layout and design of the joints is influencing strongly on the overall behaviour of the structural system. All forces and displacement are concentrated on a rather small region of the panel which is then leading to local failure. The wooden panels behaved almost completely rigid.

Therefore all the dissipated energy is resulting from the connections (local problems are highlighted by this system: e. g. if the connections coincide with gluing errors, material failures do occur). Nevertheless the hysteresis loops show an equivalent viscous damping of 14% as average. Therefore this system promises to be suitable for seismic purposes. It has a high stiffness but still good ductile and dissipating performances.

### EXPERIMENTAL BEHAVIOR OF MASONRY WALLS STRENGTHENED BY RC PLATES AND SUBJECTED TO IN-PLANE LOADS – ID 1151

*G. Russo, University of Udine, Italy*
*M. Pauletta, University of Udine, Italy*
*E. Quagliaro, Italy*

One of the main technical strategies for seismic upgrading of ordinary masonry buildings, often utilized after earthquakes, consist in strengthening walls by means of thin reinforced concrete plates applied at one or both faces of the wall and connected to it. This type of technical provision has been currently employed in Italy and widely utilized after the 1976 Friuli earthquake. In spite of this, no experimental investigation has been performed until now to assess structural behavior of the composite structure: masonry wall-reinforced concrete plates. In this work an experimental investigation has been carried out on masonry walls strengthened with different technical and executive strategies commonly used for ordinary masonry of private building. To evaluate shear strength of strengthened masonry walls, four wall test units with dimensions of 100x100x25cm and subjected to in-plane loads have been experimented. One of the walls was made of ordinary masonry, one was strengthened by a reinforced concrete plate applied only on one face, one had reinforced concrete plates on both faces but anti-adherent sheaths between the wall and the plates to simulate the case of bad realization of the upgrading, and one had plates on both faces and perfectly adherent to it. The experiments have shown an increase of 40% in shear strength of the asymmetrically strengthened wall with respect to the bare wall, as well as the importance of realizing a good adhesion between the masonry wall and the reinforced concrete plates. Indeed increases of 25% in shear strength and 60% in ductility have been observed in the composite wall with perfectly adherent plates in comparison to the composite wall with anti-adherent sheaths between the wall and the plates.

### IMPROVEMENT OF SEISMIC RESISTANCE OF ADOBE STRUCTURES – ID 146

*M. Shariful Islam, Saitama University, Japan*
*K. Honda, Saitama University, Japan*
*K. Iwashita, Saitama University, Japan*

Most losses of lives and wealth in the developing countries during earthquakes are due to the collapse of adobe houses.

In spite of this, after considering different socio-economic reasons and availability of other alternate solutions, it is expected that these types of structures will continue for the decades to come, especially in developing countries. Seismic deficiencies of adobe structures are caused by their heavy weight, brittle behavior, and low strength of the mortar. From the consideration of availability, easy construction and low cost, the current study adopts fibers (hemp, jute and straw) as reinforcement material to incorporate ductility and cement to improve strength. Uniaxial compression tests were conducted to observe the effect of fiber on strength and ductility of the adobe blocks and similar tests were conducted on fiber reinforced and cement-stabilized mortar to investigate the strength characteristics. Locally available Japanese standard clay, sand and bentonite were used to make adobe. Specimens were prepared mixing soil-sand mixture with 1% fiber. It was observed that the compressive strength of the straw and hemp reinforced adobe decreased without improving the ductility. On the contrary, the ductility of the jute reinforced adobe increased significantly with slight decrease in strength. It indicated that the jute fiber was the best option for improving the ductility of adobe. It was also observed that ductility increased significantly with the increase of jute content. But the compressive strength decreased with the increase of jute content. However, 2% jute content was the optimum to improve the ductility. Again, dry density decreased with the increase of jute content. Jute length had no effect on compressive strength and ductility. Mortar strength could be increased significantly using cement and fiber together. Shaking table tests are being conducted to study the seismic response of the reinforced adobe structures.

## ES 3g-I: Structural Engineering - Steel

Monday 13:30 - 15:00 – Room 23

### A SIMPLE DESIGN PROCEDURE FOR TIED BRACED FRAMES – ID 268

*P. P. Rossi, University of Catania, Italy*
*M. Bosco, University of Catania, Italy*
*A. Lombardo, University of Catania, Italy*

In this paper attention is focused on the definition of a design procedure of tied braced frames aiming at an optimal collapse seismic behaviour , i.e. at a global collapse mechanism characterised by quite uniform plastic rotations of links. With the aim of achieving a direct and efficient control on the value of the ultimate peak ground acceleration the procedure is founded on the displacement-based approach. In the wake of usual application of capacity design, the design internal actions of columns, ties and braces are derived from the ultimate design internal actions of links. For the sake of simplicity, the problem of the evaluation of design internal actions of ties, columns, braces and beam segments outside of links is divided into two sub-problems aiming at the definition of axial forces and bending moments of members, respectively. Design axial forces are obtained by static analysis of tied braced structures considered as pinned in correspondence of both tie and brace ends. Static analyses are carried out with reference to two different distributions of link shear values and two different distributions of lateral forces defined by means of simple relationships as a combination of the first two modes of vibration of the system. Differently, design bending moments in braces, ties and beam segments outside of links are estimated on the basis of partial structural schemes constituted by the elements which intersect the single brace-to-link node. Within such schemes bending moments transmitted by fully yielded and strain hardened links are basically distributed between braces, ties and beams as a function of their flexural stiffness. The application of the proposed procedure is shown with reference to models characterised by different number of storeys and length of links. Incremental dynamic analyses referred to ten artificially generated accelerograms give confirmation of the design hypotheses and purposes.

### EFFECTIVENESS OF A DESIGN METHOD FOR CHEVRON BRACES BASED ON THE ULTIMATE LATERAL STRENGTH – ID 230

*A. Ghersi, University of Catania, Italy*
*E. M. Marino, University of Catania, Italy*
*M. Muratore, University of Catania, Italy*

Steel chevron braced frames are able to sustain seismic forces in a very effective way, thanks to their large lateral stiffness and strength. Nevertheless their use may be limited by the design method provided by Eurocode 8 (EC8), which in some cases is overly-conservative for these systems. According to EC8, the shear strength of chevron braces is based on the buckling strength of the compressed member. It is not taken into account that, even after the buckling of the brace in compression, the brace in tension is still elastic and can sustain further force before attaining the yielding (collapse of the storey). This provides a reserve of lateral strength with respect to the design value, which becomes large for slender braces (characterised by a yielding strength much larger than the buckling strength). In consideration of the issues stated above, a new design method was developed in a recent research. According to such method the design strength of a pair of chevron braces is taken to equal the sum of post-buckling strength in compression and yielding strength in tension. This method allows reducing the cross-section size of the braces in the cases when EC8 is overly-conservative, providing at the same time adequate seismic performance. This paper compares the non-linear seismic response of a large set of chevron braced frames, designed by both the EC8 and the new method, discussing their performance and showing the advantages obtained by designing chevron braced frames according to such new method.

### RECOMMENDATIONS FOR THE EARTHQUAKE RESISTANT DESIGN OF BRACED STEEL FRAMES – ID 966

*J. Goggins, Buro Happold Engineers, UK*
*B. M. Broderick, Trinity College, Ireland*
*A. Y. Elghazouli, Imperial College, UK*

In this paper, the Eurocode 8 design approaches for concentrically braced steel frames are assessed with respect to observations and findings from shake table tests on full-scale concentrically braced single storey frames. The stiffness and resistance of the frames tested are assessed, and recommendations for estimating key response parameters are outlined. In particular, measured frame stiffnesses and natural frequencies are compared with estimates based on tension and compression brace stiffness. Several sources of member and frame overstrength, which play an important role in seismic performance and design, are identified based on the findings from the shake table tests. The tension-based design approach largely adopted in design is examined together with the member slenderness limits imposed on the bracing members. It is shown that the overstrength factor specified in Eurocode 8 for the design of the non-dissipating members of the structure may underestimate the actual behaviour. It is also observed that the bracing members with slenderness exceeding the codified limits demonstrated generally satisfactory performance. Despite lower energy dissipation, a higher fracture resistance, coupled with other practical and design advantages points towards a need to reassess the codified slenderness limits. Global ductility demands and capacities are used to assess the behaviour factors recommended for this type of structure.

### CAPACITY DESIGN PROCEDURES AND TESTING OF PERFORATED STEEL PLATE SHEAR WALLS – ID 30

*M. Bruneau, University at Buffalo, United States*
*D. Vian, Parsons Brinckerhoff, United States*

Steel plate shear walls (SPSWs) are a lateral force resisting system that has seen increased usage as a primary system in buildings over the past thirty years. Following research of the early 1980s, the use of un-stiffened and relatively thinner plates for

the infill panels was introduced, by allowing shear buckling and subsequent diagonal tension field action development in the panels as the method of lateral load resistance.

This paper present solutions to address three problems commonly encountered with SPSWs. First, in low-rise buildings with SPSWs, the minimum steel plate thickness available often far exceeds the value required from the design calculations. Building with thicker-than-required plate may lead to as-built systems that are much stiffer and stronger than designed, resulting in higher floor accelerations and force demands on retrofitted framing, and also result in concentrated hysteretic energy dissipation at individual stories along the building height. Second, design limits are needed for boundary frame members to ensure ductile behavior and prevent undesirable failure modes, to prevent column hinging, as well as to provide a robust design of the anchor beams. Finally, there is a need for a systematic way to allow utilities to pass through the plane of an SPSW.

Solutions described in this paper include special perforated SPSWs developed and tested to provide infill plates with better calibrated strength, and the passage of utilities through the wall. This paper also introduces a procedure for the efficient design of anchor beams, those beams at the upper and lowermost levels of a multi-story SPSW frame, which "anchor" the tension field forces developed in an SPSW infill panel.

### SEISMIC BEHAVIOUR OF STEEL FRAMES WITH SEMI-RIGID CONNECTIONS – ID 662

*M. Valente, Politecnico di Milano, Italy*

The seismic behaviour of steel semi-rigid beam-to-column connections is studied. The analyses were carried out by the computer code Ruaumoko at global level and by the finite element code Abaqus at local level. The analyses were validated comparing the numerical results with experimental tests performed on a two-storey steel frame prototype at the ELSA Laboratory of the JRC Ispra and on steel frames with semi-rigid connections. Non-linear static and dynamic analyses were carried out in order to highlight the different behaviour variyng the stiffness and the strength of the connections. Different damage index were evaluated to estimate the global and local damage. Parametric analyses on the behaviour of bolted extended end-plate connections using finite element models are carried out. The analytical models take account material nonlinearities, geometrical discontinuities and large displacements. Failure modes and stress and strain concentration are highlighted in the models. The analyses of the results shows that semi-rigid moment resisting frames could be an adequate structural solution in seismic zone.

## ES 3g-II: Structural Engineering - Steel

Monday 15:30 - 17:00 – Room 23

### CORRELATION BETWEEN LOCAL AND GLOBAL CYCLICAL STRUCTURAL CAPACITY OF SMR FRAMES – ID 1027

*E. Bojórquez, Institute of Engineering, University of Mexico, Mexico*
*A. Díaz, Institute of Engineering, University of Mexico, Mexico*
*S. Ruiz, Institute of Engineering, University of Mexico, Mexico*
*A. Terán-Gilmore, Department of Materials, Autonomous Metropolitan U, Mexico*

INTRODUCTION AND JUSTIFICATION: Performance-based seismic design requires the use of reasonable tools to estimate structural damage within numerical design methodologies. In certain cases, the effect of cumulative plastic deformation demands should be accounted for during the estimation of structural damage.

Experimental and analythical evidence carried out in steel members suggest that the linear cumulative damage index can be used to obtain reasonable estimates of structural damage. This index is formulated as a function of both the cyclic structural demand and capacity of the element or earthquake-resistant system. Within this context, the capacity of the system is defined in terms of the load cycles (N) the structure is able to undergo to a given ductility demand. A challenge remains around the practical use of damage indices for the design of actual structures.

OBJECTIVE: The aim of this paper is to estimate the cyclic global capacity of several steel moment-resisting frames based on experimental results performed on structural steel members.

METHODOLOGY: Eight standard occupation buildings with different seismic yielding coefficients and fundamental periods of vibration were designed according to the Mexico City Building Code. "Push-over" analyses are performed on those structures in order to correlate the maximum local ductility of the elements with the global ductility capacity of the frames. The comparison is established in maximum and cyclic deformation capacity terms.

RESULTS: A high correlation between the local and the global ductility capacity of the frames was observed. An expression to evaluate the number of cycles that a regular steel frame is able to resist is formulated as a function of its design seismic coefficient, fundamental period of vibration and local deformation capacity. Some examples to evaluate structural damage in complex structures (taking into account cumulative plastic demands) through the use of simple models are presented.

### ON THE ACCURACY OF PUSHOVER ANALYSIS FOR ESTIMATING THE SEISMIC BEHAVIOR OF BRACED STEEL FRAMES – ID 102

*I. Hajirasouliha, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. Moghaddam, Sharif University of Technology, Iran (Islamic Republic Of)*

This paper investigates the potentialities of the pushover analysis to estimate the seismic deformation demands of concentrically braced steel frames. Reliability of the pushover analysis has been verified by conducting nonlinear dynamic analysis on 5, 10 and 15 story frames subjected to 15 synthetic earthquake records representing a design spectrum. It is shown that pushover analysis with predetermined lateral load pattern provides questionable estimates of inter-story drift. To overcome this inadequacy, a simplified analytical model for seismic response prediction of concentrically braced frames is proposed. In this approach, a multistory frame is reduced to an equivalent shear-building model by performing a pushover analysis. A Conventional shear-building model has been modified by introducing supplementary springs to account for flexural displacements in addition to shear displacements. It is shown that modified shear-building models have a better estimation for the nonlinear dynamic response of real framed structures compare to nonlinear static procedures.

### APPLICABILITY OF MODERN SEISMIC CODES TO EXISTING STEEL STRUCTURES – ID 1035

*B. Hoffmeister, RWTH, Steel Structures, Germany*

This contribution deals with the assessment of seismic resistance of steel structures which have initially been designed without considering seismic actions. This situation is common to moderate seismic regions, where recently introduced seismic design requirements demand safety checks in particular of important or strategic structures. The verification of sufficient seismic resistance becomes mandatory for structures which are subject to structural modifications, e.g. due to modified operational conditions and changed loads. In such cases a complete structural analysis including the verification of seismic resistance is required. The verification has to consider the mechanical properties of materials and connections used in the past, the adequacy of details (in particular connections and anchorages) and the actions and safety factors applied in the initial design. Particular attention has to be paid to differences between the earlier global safety concept and the partial safety concepts. This includes the consideration of an appropriate importance factor depending on the consequences of

failure or partial damage of the structure. From the analysis of the existing structure and of the initial design, available margins of safety as well as potential weak points can be determined, allowing to utilise available resistance reserves and to adapt structural parts to the additional requirements. Improvements of the structural response in terms of dissipative behaviour can also be achieved depending on the structural topology and on the possibility to comply with capacity design requirements. The contribution is completed by practical examples of existing industrial structures which have been checked in order to verify their seismic resistance according to new codes. A special case of a granite mill has also been investigated which has been completely moved from a non seismic region in Germany to Serbian region of significant seismicity.

### PROTOTYPE FOR EARTHQUAKE-RESISTANT RESIDENTIAL BUILDINGS COMBINING STEEL FRAMES WITH LOCAL MATERIALS – ID 373

*T. M. Swain, Bauhaus-Universitaet Weimar, Germany*
*J. Schwarz, Bauhaus-Universitaet Weimar, Germany*

While steel is frequently used in infrastructure, high-rise and industrial buildings, presently it is rarely applied for small residential units, one reason being the high degree of preprocessing necessary. However, it is proven that steel is an appropriate material for achieving high seismic resistance. The solution presented in this paper seeks to eliminate economical disadvantages by providing a modular system, using standard elements to assemble residential units of varying size and shape. For the basic structural steel system eccentric bracings are recommended. While moment-resisting frames were discarded as uneconomic, doubts about the ductility of concentrically braced frames are raised, resulting in the recommendation for restricting the behaviour factor for such systems. The steel frame is flexible, allowing for storey drifts up to 10 cm; the infill walls are merely required to support their own weight, but must not interact in a destructive way with the steel frame, which is achieved by movement gaps. Key elements of the system are special uniaxial couplings between the walls and the steel frame. Reinforcement of the walls by application of synthetic grids is recommended in areas with very high hazard. Tests carried out in October 2004 confirmed the functionality of the prototype system.

The system can be applied to small or medium-size residential homes (up to 3 stories) in earthquake regions around the world. While the steel frame should be provided by a specialised steel company, local materials, techniques and labour can be used for secondary parts. An example of an architectural design for Turkey, which retains elements of local architecture and identity, is shown.

The paper summarises results from the research project Steel Earthquake Design carried out by the Bauhaus-Universität Weimar in cooperation with Rudolstaedter Stahlbau GmbH and funded by the German Ministry of Economy.

### LARGE STEEL TRUSS BRIDGES OF THE TAIWAN HIGH SPEED RAILWAY – ID 1450

*E. Los, HOCHTIEF Construction AG, Germany*
*S. Sciani, HOCHTIEF Construction AG, Germany*
*M. Dr. Empelmann, HOCHTIEF Construction AG, Germany*
*D. Dr. Nowak, HOCHTIEF Construction AG, Germany*

The US$15 billion Taiwan High Speed Rail Project, one of the largest and most challenging infrastructure projects in the world to date, is scheduled to commence services by the end of 2006. The civil works were constructed under twelve separate designs and build contracts. The Contract C250 (the contractor HBP is a joint venture of HOCHTIEF AG, Ballast Nedam and Pan Asia) includes approximately 39 km of viaduct and bridge construction (both, con-crete and steel), short lengths of cut and cover tunnel and earthworks, and various other structures and buildings.

In particular, the three alongside located warren steel truss bridges, each 410m long, with spans of 150m-120m-140m and a total of more than 25,000 tons of structural steel, are a certain speciality and highlight in Lot C250, and in the entire Taiwan High Speed Railway project, with regard to design and construction.

Capacity design methods used for the seismic resistant design of the 3-span bridges are described in connection with Taiwan's high level of seismic activity, as was evidenced by the 1999 Mw = 7.6 Chi-Chi earthquake, and several other large earthquakes which have struck the island in recent decades.

The bridges are also remarkable due to their construction method mainly influenced by their geographic location. A 6-lane Highway, a 4-lane county road and a major river of Taiwan had to be crossed. Furthermore, the vicinity of the new Taichung Station caused interfaces, which need to be considered during erection. The bridges were constructed by incremental launching with a free cantilever of 130m, which is likely to be one of the world-wide longest ever launched bridge span for that kind of steel bridge structure.

## ES 3h: Structural Engineering - Miscellaneous

Thursday 10:45 - 12:15 – Room 21

### BEATING EFFECT IDENTIFIED FROM SEISMIC RESPONSES OF FOUR BUILDINGS – ID 378

*M. Celebi, USGS, United States*
*D. Rinaldis, ENEA, Italy*

As more earthquake records from instrumented buildings become available, beating effects are identified in the response of the buildings. This prompts us to revisit the subject of beating effect as this particular response characteristic may impact the instantaneous and long-term shaking performance of the buildings during earthquakes. Beating effect is a dynamic characteristic observed in some buildings and is exhibited by a periodic, repeating, resonating and elongating vibrational behavior caused by distinctive close coupling of translational and torsional modes of a structure. Thus, repetitively stored potential energy during the coupled translational and torsional deformations turns into repetitive vibrational energy causing the ensuing periodic, repeating, resonating and elongated motions. The beating becomes severe if the system is lightly damped. The beat frequency generally known in acoustical physics is denoted by the absolute value of the differences in frequencies that cause the phenomenon. However, it is noted that resonance caused by site effects also contributes to the beating effect.

The purpose of this paper is to present four cases of structural responses that exhibit beating effect that may impose negative impact on the behavior and performance of a building. Spectral analyses and system identification techniques are used to quantify dynamic characteristics used in computing beating periods. Engineering implications of the beating effect are:

• Elongated cyclic shaking due to beating effect takes its toll on the structural system – particularly if the structure is brittle and old (historical buildings). • Repetitive shaking accentuates fatigue and low-cycle fatigue. • Beating cycles can and do cause discomfort to occupants.

Identification of beating effects is the key to find remedial action in modification of dynamic characteristics in order to attenuate or eliminate such effects. One of the four buildings retrofitted to alter its response characteristics to attenuate or eliminate beating effect.

### DIMENSIONAL ANALYSIS OF SOIL-STRUCTURE INTERACTION – ID 931

*P. Roussillon, BRGM, France*
*C. Boutin, ENTPE, France*

Soil-structure interaction (SSI) has been widely studied in the past three decades. Sophisticated numerical methods have been developed that already allow, or will in the long term make it possible, to treat most engineering problems. However, the authors have noticed a lack of a simple, synthetic, physical review of expected SSI effects on current buildings, to be used for in-situ testing, vulnerability diagnoses, code seismic loads, etc. We

present a dimensional and parametric analysis of soil-structure interaction, coupling simple, though realistic models, of structures and soil-foundation systems. A continuous beam, including the effects of bending, shear and rotational inertia of section, is sufficient to dynamically characterize most regular buildings, in particular their specific transmission of shear force and momentum at the soil-structure interface. Closed-form impedances given by the cone model approach are used to introduce the foundation compliance and energy radiation into a soft homogeneous visco-elastic soil. The study highlights the dimensional parameters that govern the main mechanism of the phenomenon: geometrical effect, rigidity contrast, and their influence on the complex modal features of the system. The given results allow a better physical insight into SSI, at least in its fundamental aspects, as well as a first, reasonably accurate estimate of the importance of the phenomenon. This is particularly true for the first mode whose frequency shift and radiation damping prove to be almost independent of the specific behaviour of the building.

### INVESTIGATION OF POUNDING DAMAGE FOR REINFORCED CONCRETE STRUCTURES WITH LIMITED DUCTILITY – ID 607

*M. M. Said, Cairo Univ., Egypt*
*A. F. Hassan, Cairo Univ., Egypt*
*S. A. Mourad, Cairo Univ., Egypt*

Seismic pounding has been one of the causes of severe structural damage to adjacent buildings in metropolitan areas struck by past earthquakes. In some cases, the additional forces generated by the impact between colliding structures have lead to structural collapse. In other cases, the buildings sustained local damage, indicating that structural pounding may be a serious threat to the structures if a stronger earthquake takes place. Damage due to pounding may extend to loosen or damage cladding materials, thus endangering pedestrians below. Pounding takes place whenever separation distance is not sufficient to accommodate the relative displacement. The objective of this research is to investigate seismic pounding between adjoining buildings and the factors contributing to its occurrence and severity. These buildings are assumed as existing old structures not designed according to recent codes requirements for earthquakes resistance. The studied factors are the separation distance, the dynamic characteristics of colliding buildings, and intensity and characteristics of incident earthquakes. Through non linear time history analyses of seven different ground motion records, using OPENSEES software, effect of afore-mentioned factors on the behaviour of a series of five MDOF prototype reinforced concrete buildings with 7, 10, 15 and 20 floors height. Safe separation distance between these buildings is evaluated according to EURO code 8 requirements. The parametric study assumes five different separation distances; namely 0%, 25%, 50%, 75% and 100% of the safe separation dustance. To emphasise and depict the effect of pounding on the subject buildings, parametric study results are compared to those corresponding to no-pounding analyses. The adequacy of EURO code 8 provisions to preclude pounding between buildings of different heights and stiffnesses under different earthquakes are evaluated. Results of this parametric study are interpreted and correlated with previous studies. Finally, precautions are outlined to minimize the damaging effect of pounding.

### NEURAL NETWORK-BASED CONSTITUTIVE MODEL FOR CYCLIC BEHAVIOR OF MATERIALS – ID 392

*G. Yun, University of Illinois at Urbana-Champaign, United States*
*J. Ghaboussi, University of Illinois at Urbana-Champaign, United States*
*A. Elnashai, University of Illinois at Urbana-Champaign, United States*

Inelastic analyses of structures play an important role in assessing the performance of structures under cyclic loads such as the earthquake loading. Plasticity models with various hardening rules, such as kinematic and isotropic hardening, have been proposed and used in numerical simulations. The primary limitations of these models are encountered when dealing with cyclic behavior of materials. A novel neural network-based model is presented in this paper for representing the cyclic behavior of materials. New implicit internal variables are introduced establish unique relationships between the input and output of the neural network material models during the cyclic response of the material. The proposed neural network based model is capable of learning and representing the complex inelastic hysteretic behavior of materials and structural components. A mathematical proof of the functional relationship is provided for the admissible hysteretic curves. This proof is valid for both the stress and strain control forms. Following the new internal variables for the proposed cyclic material model, a novel neural network representation is proposed. The proposed model fundamentally differs from the previously proposed neural network based cyclic material models. It is mainly based on energy description, different from the conventional phenomenological hardening-based plasticity models. The algorithmic material tangent stiffness matrix is derived and implemented as a user-defined material module in the widely used commercial finite element code, ABAQUS. Illustrative examples of cyclic behavior of uni-axial plain concrete and metal are presented. The performance of the proposed model in multi-dimensional problems is demonstrated through a 2-D beam-column connection problem.

KEY WORDS: Cyclic Plasticity Model; Neural Networks; Hysteretic Systems; Nonlinear Finite Element Analysis

### DAMAGE EVALUATION IN R/C SHEAR WALLS USING THE DAMAGE INDEX OF PARK AND ANG – ID 165

*C. Oyarzo Vera, Universidad Catolica de la Santisima Concepcion, Chile*

The damage indeces are a concept introduced in the last years by some researchers, which had the particularity that they can measure the damage on a defined scale (0 to 1). These indeces have become an important tool for the evaluation of the damage on the structures, but also they could became a design variable in performance based design.

One of the most used is the Damage Index of Park & Ang, which considers the damage due the deformations over the elastic stage and the cumulative effect of reversible loads.

This index was made to quantify the damage in slender structural elements (beams or columns) which generally fail by flexion, this situation establishes a limitation for its use in buildings constructed according to the chilean practice, because they are generally structured with shear walls, which present a low slenderness.

This research pretends to show that it is not possible to use directly the equations proposed by Park & Ang to non-slender elements, because the parameter betha included in this Damage Index depends on other variables, which are not considered by the authors. It is possible to detect important differences in the values of parameter betha and in the damage index, itself.

Some of these variables would be: the loads history, the degradation level, the type of fault observed in the testing wall and the cumulative ductility of displacement recorded during the test.

Another interesting fact is that the values of betha obtained using experimental data, seems to be more related to the cumulative ductility recorded on the failure, than the displacement reached at the same situation.

All this facts show that it is necessary obtain a new equation for betha to represent in a better way the behavior of non-slender elements.

### FRP IN CIVIL STRUCTURES - REHABILITATION AND NEW CONSTRUCTION – ID 1441

*T. Necdet, Istanbul Technical University, Turkey*

Polymer composites (FRP), which may be used for retrofitting of existing buildings and construction of new structures, is a new area for civil engineers. Although FRP products are relatively expensive, in many cases it becomes more beneficial than classic

construction and retrofitting techniques, if FRP system is selected and applied correctly. The aim of this study is to summarize the general information on FRP systems for engineers and researchers, who are willing to use FRP systems as an alternative retrofitting technique.

In this paper physical and mechanical behaviors of main contents of FRP, which are fibers and polymer (epoxy), are described. The important characteristics of fiber types (carbon, glass and aramid) are explained. The advantages and disadvantages of FRP are presented.

The critera for selection of suitable combination of fiber and polymer types is summarized and presented in tables comparatively. The selection of most effective FRP systems for different purposes primarily depends on the objective of retrofitting, type of structural element where FRP is applied (column,beam...etc), type of the load that FRP and structural element is subjected and the environmental conditions that FRP is exposed to.

The description and usage of different types of FRP systems are presented. These are FRP fabrics, surface mounted FRP rods, FRP molded sheets, FRP prestress cables, FRP truss, and FRP panel systems. The application procedures of this FRP systems are explained in details, as well as structural behavior and different application styles.

The important application difficulties are described with different alternative solutions, such as anchoring. Some of the international codes on FRP are listed and the most important precautions for application suggested in codes are discussed. The paper is concluded with the remarks on quality control demands for application of FRP systems, cost evaluation and new research areas on FRP.

## ES 4-I: Design Criteria and Methods, Codes

Thursday 10:45 - 12:15 – Room 4

### PERFORMANCE-BASED ENGINEERING CONCEPTS: PAST, PRESENT AND FUTURE – ID 77

*P. Negro, JRC, Italy*
*E. Mola, Politecnico di Milano, Italy*

The development of a fully performance based approach and framework to civil engineering appears to be the path that both the research and the normative communities have chosen to pursue for the near future. Indeed, such a choice entails a great effort in re-defining the basic concepts at the basis of the current design and codification philosophy in a harmonized, self-sufficient, coherent and non-misleading way; on the other hand, such an effort is deemed to pay off as a performance based approach to civil engineering is for sure a new, more mature, comprehensive and higher profile one, with respect to traditional prescriptive regulations and design procedures. The present paper aims at clarifying the basic aspects of performance-based concepts in civil engineering and at pointing out the main steps of their progressive implementation into normative documents and design guidelines. At first, introduction on the basic terminology and concepts in given, based on a review of the most recent research efforts on the matter; following to that, a short review of the state-of-the-art in the research and codification of PB engineering concepts is carried out, with a particular focus on the advancements made in the USA, Europe and Japan. Finally, a possible scheme for the classification of current and future normative documents based on their content in PB concepts is presented and outlined through a case study. In the end, some conclusions regarding the current needs and future developments in the field of classification and standardization of PB normative documents are drawn.

### VERIFICATION OF SOME EUROCODE 8 RULES FOR SIMPLIFIED ANALYSIS OF STRUCTURES – ID 1090

*J. P. Angel, ROSE School, Italy*
*R. Pinho, University of Pavia, Italy*
*H. Crowley, EUCENTRE, Italy*

EUROCODE 8 presents several rules for simplified analysis of structures. This work focuses on three of those rules: the expression used to estimate the fundamental period of free vibration, the use of the reduction factor lambda, and the implication that equivalent linear analysis can only be used for buildings that are regular in height. Several models are analyzed in order to verify the appropriateness of these rules. The first rule uses the expression T1=C1*H∧(3/4) to estimate the fundamental period of free vibration. This equation was developed for Californian buildings that might have different materials, configuration and construction parameters than the European structures and may not be applicable in all cases. The second rule states that the reduction factor lambda is equal to 0.85 when a building is at least 3-storey high and has a fundamental period of free vibration lower than 2Tc. The aim of the analysis is to ensure that the use of this factor does not lead to an underestimation of the seismic loads. In the last rule, the use of equivalent linear analysis is forbidden for irregular buildings in height. The verification is intended to show that equivalent linear analysis actually over predicts the seismic loads for this condition.

### ACCOUNTING FOR RESIDUAL DEFORMATIONS AND SIMPLE APPROACHES TO THEIR MITIGATION – ID 343

*D. Pettinga, ROSE School, Italy*
*S. Pampanin, University of Canterbury, New Zealand*
*C. Christopoulos, University of Toronto, Canada*
*N. Priestley, ROSE School, Italy*

Recent developments in performance-based seismic design and assessment approaches have emphasised the importance in properly assessing and limiting the residual (permanent) deformations, typically sustained by a structure after a seismic event, even when designed according to current code provisions.

A comprehensive performance-based design and assessment framework has been proposed by the authors, in which residual local and global deformations can be explicitly taken into account through the introduction of a Residual Deformation Damage Index (RDDI). From this concept a performance-based matrix combining maximum deformation/displacement and residual deformation/displacement parameters has also been adopted. Based on this a Direct Displacement-Based Design (DDBD) approach which includes an explicit consideration of the expected residual deformations has been developed to account for both 2 and 3-dimensional MDOF effects.

Having estimated the possible residual deformations in a structure, it remains to implement specific design features to reduce them to an acceptable level. A series of simple approaches to increasing the system post-yield stiffness are proposed here, and demonstrated through both non-linear pushover and time-history analyses to be effective at achieving their intended goal of residual deformation reduction.

### A PROBABILISTIC FRAMEWORK FOR PERFORMANCE-BASED SEISMIC ASSESSMENT CONSIDERING RESIDUAL DEFORMATIONS – ID 731

*U. S R, University of Canterbury, New Zealand*
*S. Pampanin, University of Canterbury, New Zealand*
*C. Christopoulos, University of Toronto, Canada*

Recent advances in performance based design and assessment procedures have highlighted the importance of considering residual deformation in addition to maximum deformation as a complementary damage indicators. A 3-dimensional performance matrix, where maximum and residual deformations are combined to identify performance levels coupled with various seismic intensity levels, has been recently presented by the authors for either seismic design or assessment. In this first formulation of a complete framework for performance based pro-cedures considering residual deformation a deterministic approach has been followed.

In this paper, the concept of a jointed performance matrix is presented under a probabilistic formulation along with the full performance based procedures. Jointed fragility curves ex-pressing the probability of exceedence of performance levels defined by pairs of maximum-residual deformations are derived using bivariate probability distributions, due to the statisti-cal dependence of the two parameters. With the proposed formulation, the achievement of performance objectives, connecting defined performance levels at increasing intensity levels, can be targeted with certain level of confidence.

After a conceptual presentation of the overall probabilistic formulation, numerical examples on the evaluation of the seismic performance of equivalent SDOF systems designed according to Displacement Based Design approach are presented. Extensive non-linear time history analyses under a properly selected suite of earthquakes are performed. Alternative hysteretic systems are modeled assuming lumped plasticity.

The significance of including the residual deformations with maximum deformation indices in predicting the actual performance level is confirmed and its extent of influence is discussed. It is shown that fragility curves obtained for performance levels corresponding to only maxi-mum drift limits represent higher damage state when combined with residual drift limits, thus, further highlighting the crucial need for accounting for residual responses in performance as-sessment and design procedures. Based on the results, suggestions on structural properties ap-propriate to practical design applications will be included.

### AN EQUIVALENT DAMPING MODEL FOR DIRECT DISPLACEMENT-BASED DESIGN – ID 1473

*B. Farahmand, Sharif University of Technology, Iran (Islamic Republic Of)*
*M. A. Ghannad, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. H. Jafarieh, Sharif University of Technology, Iran (Islamic Republic Of)*

Recently, the traditional strength-based design philosophy is being replaced by more relevant displacement-based design (DBD) approach. As a main step, DBD method requires a simplified procedure to estimate the inelastic displacement demands of the structure. This step is usually done by either replacing the non-linear system by an equivalent linear system or employing the well-known concepts of inelastic design spectra. The former considers the use of an equivalent linear system represented by an equivalent elastic spectrum, which is associated with an effective damping ratio, to estimate the nonlinear response. Thus, the idea of using the effective damping model has been widely used in the displacement-based design and several effective damping models have been proposed. In this research, the accuracy of different proposed models for effective damping of the equivalent linear system is assessed through comparison of target ductilities with ductility demands result from precise non-linear time history analyses. For this purpose, some typical examples have been designed, using DBD approach, with the concept of equivalent linear system, using different effective damping models. Then, inelastic dynamic time history analysis has been performed for designed examples subjected to a number of design spectrum compatible artificial records. The difference between the resulted ductility demands are then compared with the initial target ductilities for different cases. Finally, a modified damping model has been proposed which has a better agreement with the non-linear time history analysis results.

## ES 4-II: Design Criteria and Methods, Codes

Friday 10:45 - 12:15 – Room 4

### ENERGY-BASED NON-LINEAR STATIC ANALYSIS – ID 1178

*A. Parducci, University of Perugia, Italy*
*F. Comodini, University of Perugia, Italy*
*M. Lucarelli, University of Perugia, Italy*
*M. Mezzi, University of Perugia, Italy*
*E. Tomassoli, University of Perugia, Italy*

DEFINING THE PROBLEM Over the past few years, of all the methods available for the analysis of post-elastic behaviour of buildings under seismic inputs, that of non-linear static analysis or pushover analysis has been constantly increasing. This method is simpler than dynamic non-linear analysis, and whenever it is compared to conventional linear analysis, it emerges as a more realistic means of interpretation of dissipative mechanisms and expected structural damage. Recent guidelines make reference to this method. The application of non-linear static analysis may cause problems when it comes to defining the SDOF system capacity curve, corresponding to the real structure, where to find, through the comparison with the design eartquake demand spectrum, the design displacement to be attributed to a conventionally defined point on the real structure. SELECTING THE APPROACH This paper defines an energy-based approach to pushover analysis upon the consideration that the energy released by a structure under seismic inputs must be dissipated through the controlled damage of its elements. Via this approach, a distribution of increasing horizontal forces is imposed onto a non-linear mathematic model while the energy that the storey forces release to the effective system is calculated step by step so as to obtain the pushover curve. The resulting SDOF curve is defined as the one that equals the work performed by the real system, step by step. Integrating the pushover curve leads to an energetic capacity curve. SUBSEQUENT RESULTS AND APPLICATIONS The direct comparison of the capacity curve in energy terms and the spectrum of energy released by the seismic input makes it possible to determine the displacemnet of the SDOF equivalent system, to obtain the deformed configuration of the MDOF system and to check local damage immediately.

### STRENGTH DEMAND DIAGRAM BASED ON CONSTANT DAMAGE CONCEPT – ID 1710

*P. Panyakapo, Sripatum University, Thailand*

In this paper, the strength demand based on constant-damage concept is proposed for performance-based design. The design approach is called Constant-Damage Strength Demand Diagram. This is presented as a graphical plot of strength demand, which is required to limit the seismic damage to a target value, against the displacement of the structures, whereas the natural periods of the systems are represented by the radical lines. The strength demand diagrams are computed by nonlinear response analysis for systems which are subjected to 38 earthquake records for rock sites and 36 earthquake records for soft soil sites. The elastic perfectly plastic model is selected as the hysteretic behavior of structures. It is found that the strength demands for soft soil sites are dominant when the natural periods of structures are close to the predominant period of ground motion. The diagrams are also presented in terms of simplified expressions, which are the relationships of important parameters, i.e., strength demand, displacement, elastic base shear coefficient, strength reduction factor for target seismic damage, target ductility ratio, and natural period of vibration. The investigation on its applicability confirms that the diagrams provide uniform levels of seismic damage throughout the whole natural periods range.

### PERFORMANCE DOMAIN DESIGN PROCEDURE OF WALL BUILDINGS – ID 822

*I. Guljas, University of Osijek, Croatia (Local Name: Hrvatska)*
*V. Sigmund, University of Osijek, Croatia (Local Name: Hrvatska)*

In order to develop a new design, the designer faces a few numbers of preliminary designs and risk iterations to determine the most efficient structure. Similarly, in the case of reinforced concrete wall buildings, analysis is usually very complicated and time consuming only to find out that following minimum

requirement was sufficient in the first place (due to the usually high wall-to-floor ratio). To simplify the design of structural wall buildings, a conceptual design approach is proposed which allows the designer to incorporate ductility or deformation-based response parameters into the initial phase of the design process.

The proposed "Performance domain" procedure considers multiple performance levels and makes calculation simpler, establishes the minimum material requests that correspond closer to reality and enable building of safer and less expensive structural wall buildings. The desired performance levels correspond to demand and ideally this procedure involves a minimum of design effort. It is based on results obtained in parametric analysis as well as on extensive library of experimental data. The design procedure starts with the specification of desired performance objectives for the entire structural system, given the hazardous environment in which it is to be constructed, and then provides a direct rational path by which the structure may be designed to attain these goals.

The structural response limits are given by means of acceptability diagrams obtained through nonlinear response of various model wall buildings to a set of ground motions. The benefits of such methodology tend to be in improved understanding of the seismic performance of buildings. It should produce predictable and consistent seismic protection for new structures. In the paper, the method is described and discussed, and its basic derivations are given. Application of the method is illustrated by means of an example.

### SEISMIC PERFORMANCE AND DESIGN OF COMPOSITE MOMENT-RESISTING FRAMES – ID 605

*J. M. Castro, Imperial College London, UK*
*A. Y. Elghazouli, Imperial College London, UK*
*B. A. Izzuddin, Imperial College London, UK*

Composite steel-concrete structures are widely employed in Europe and elsewhere due to their relative merits in comparison with other systems in terms of structural behaviour as well as speed and efficiency of construction. In particular, under seismic loading, the favourable performance of composite frames due to enhanced strength and ductility has been recognized for many years. Consequently, most seismic codes provide specific provisions for the design of various composite frame configurations. In Eurocode 8, seismic design of composite structures is based on traditional force-based principles which adopt the concept of behaviour (or force reduction) factors to reduce the elastic strength demand in accordance with the expected ductility capacity. For the particular case of moment-resisting frames, the behaviour factors proposed are the same as those provided for steel frames. This simplified approach however does not account for the significant overstrength observed in composite structures. The level of overstrength can be shown to be directly related to gravity loading design requirements. In order to assess the levels of overstrength present in typical composite moment-resisting frame systems, extensive parametric studies including nonlinear static as well as dynamic time-history analyses are described in this paper. The investigation illustrates the influence of geometric considerations, design factors and seismic zonation parameters on the actual performance of composite moment-resisting frames, especially in terms of strength and ductility issues. The findings reveal that composite moment-resisting frames designed according to Eurocode 8 perform in a remarkably different way from that predicted by the code. Recommendations for addressing these important effects through modifications to the code procedures are proposed, and their influence on achieving a more rational and realistic design approach are illustrated.

### ON THE USE OF PUSHOVER ANALYSIS FOR EXISTING MASONRY BUILDINGS – ID 1080

*A. Galasco, University of Genova, Italy*
*S. Lagomarsino, University of Genova, Italy*
*A. Penna, EUCENTRE, Italy*

The application of nonlinear static (pushover) procedures for the assessment of existing masonry buildings has been introduced into seismic codes (e.g. EC8, new Italian Code OPCM 3274/03), but its implementation to real structures still presents several critical point. The 3-dimensional model of a masonry building can be obtained by assembling flame-type macro-element models of the walls and orthotropic membrane elements in order to represent the mechanical behaviour of flexible floors. This modellization, although very effective in representing the actual behaviour (TREMURI program), does not allow to use common simplifications such as rigid floor motion. Moreover, a 3D pushover algorithm requires a predefined pattern of horizontal forces to be applied to the structure and, maintaining constant the relative force ratios, the horizontal displacement of a control node to be incremented. Several authors suggested to avoid the problem of the dependence on the force distribution by adopting adaptive load or displacement patterns, considering multi-modal distributions updated on the basis of the structural damage. A new displacement-based algorithm for the adaptive pushover analysis of masonry walls and buildings is presented: the load pattern, in this case, is directly derived, step-by-step, by the actual deformed shape evaluated during the pushover analysis. The choice of the control d.o.f. may also be critical as well as the conversion of the m.d.o.f. structure pushover curve into the lateral capacity curve of an equivalent nonlinear s.d.o.f. system. Several non-linear dynamic analyses have been then performed in order to directly evaluate the inertial force distribution and to compare the displacement demand with the one predicted by the static procedures. The PDB adaptive procedure seems to be very powerful for in-plane wall analyses, whilst it requires some corrections in order to be applied to 3-dimensional masonry buildings.

## ES 4-III: Design Criteria and Methods, Codes

Friday 13:30 - 15:00 – Room 4

### THE EUROPEAN STANDARD ON ANTI-SEISMIC DEVICES PREN 15129 – ID 1480

*M. Dolce, University of Basilicata, Italy*
*P. Bisch, ENPC, France*
*K. Fuller, TARRC, UK*
*R. Medeot, Consultant, Italy*
*S. Infanti, FIP, Italy*

In 2001 the European Committee for Standardization (CEN) created the Technical Committee CEN-TC-340: Anti-seismic Devices. Its scope is to draw a European Standard that covers the design of devices that are provided in structures designed in accordance with EUROCODE 8, with the aim of modifying their response to the seismic action. It specifies functional requirements and general design rules in the seismic situation, material characteristics, manufacturing and testing requirements, as well as acceptance, installation and maintenance criteria. Rigid Connection Devices (including Permanent Connection Devices, Fuse Restraints, Temporary (Dynamic) Connection Devices), Displacement Dependent Devices (Linear devices, Non-linear devices), Velocity Dependent Devices (including hydraulic dampers), Isolators (i.e. devices that are deputed to support vertical loads, such as elastomeric isolators, sliding bearings) and combinations of devices are dealt with in specific clauses. General design rules, evaluation of conformity, installation an in-service inspection are the object of other general clauses that guarantee a uniform approach to the problem. The final draft of the European Standard on Anti-seismic Devices was completed on June 2004. Comments received during the Public Enquiry have been examined for possible implementation. Next version of the Standard will be delivered by September 2006 for a new enquiry. The European Standard on Anti-seismic Devices prEN 15129 represents the most complete and up-to-date document in this field presently available to seismic design engineers and seismic hardware manufacturers. Indeed, it aims to cover all types of existing seismic hardware, while leaving a door open to future progress, this Standard being highly performance-oriented. This feature also constitutes per se a guarantee of equity among the

various systems that may be used as alternatives. The paper illustrates the structure of the European Standard, the criteria adopted in its drafting and some of the aspects which render this document unique and innovative.

### INFLUENCE OF SOME VARIABLES ON THE SEISMIC INCREMENT ORDINATES FOR IMPORTANT STRUCTURES – ID 284

*J. García-Pérez, Instituto de Ingeniería, Mexico*
*O. Díaz-López, Instituto de Ingeniería, Mexico*

OBJECTIVE. The paper analyzes how the seismic design coefficient increment for important structures vary according to different concepts such as peak ground saturation, initial costs, structural capacity, and uncertainties in different parameters. The approach used is based on the total cost design criterion, including the initial cost as well as the costs due to earthquakes occurrence. Three different sites are under study: a site in the near-field, a site far away from the source, and a site at a moderate distance between those two sites.

FORMULATION, METHODS AND CASES STUDIED. We consider that the design is such that it minimizes the expected present value of the total cost, including initial and maintenance costs as well as losses due to damage and failure. As a first approach we assume that the incremental factor in the design parameter of important structures, at one of the sites, is optimum; after that we compute the corresponding factors for the other sites. The earthquake generation process comprises background activity as well as characteristic earthquakes. For sites located in the near-field a saturation phenomenon is considered in the peak ground acceleration as the magnitude of the earthquake increases. This phenomenon, the initial costs of structures as well as uncertainties in some parameters are considered in order to see their influence on the values of the incremental factor at the different sites studied. The influence is measured by comparing the variations in the total costs.

CONCLUSIONS. Incremental factors for important structures at three sites are computed considering that the design criterion minimizes the total cost. The influence of different variables and their uncertainties on these factors are studied. Preliminary results show that these factors can vary according to the site seismicity, and that their increment when uncertainties in some parameters are taken into account, is appreciable.

### USE OF COUPLED AND REGULATORY METHODS IN SEISMIC SOIL-STRUCTURE INTERACTION FOR NUCLEAR PLANTS AND DAMS – ID 210

*V. Guyonvarh, EDF/R&D, France*
*G. Devesa, EDF/R&D, France*

Taking into account soil structure interaction (SSI) methods is needed because higher levels for seismic solicitations are required in the design of new nuclear plant projects or to determine remaining margins on structures already dimensioned with conservative methods. At EDF, a numerical SSI method is applied based on sub-structuration and frequency resolution, which couples a finite element method (FEM) software: Code_Aster® and a boundary element method (BEM) software: ProMISS3D®. It is compared to a simplified design method usually applied in regulatory studies of nuclear plants. It consists of soil springs, located below the foundation, the stifness of which needs to be determined The use of one or both methods will be illustrated on these representative examples : · comparison of both methods on the seismic response of a nuclear building with varying homogeneous soil modulis from soft (about 800 MPa) to hard (7000 MPa) behaviour; · parametrical study of soil modulus, soil structure connection and depth of foundation on a buried nuclear building using the coupled frequency method; · combined use of both methods : the design method is used to determine the reduced interface modes of a soft foundation; · the use of the design method to determine soil springs with unilateral compressive behaviour and then the study of the basemat uplift of a nuclear building from time history dynamical calculation with the FEM calculation software; · dynamic behaviour of a earth dam with an impervious water face membrane under seismic loading from a 3D model where storage basin, mountain and fundation near the structrure are taken into account. The whole SSI method is implemented into the Code_Aster® finite element software wich is developed at EDF under quality procedures. Code_Aster® is available through general public licence by downloading from its website.

### THE SEISMIC RESPONSE MODIFICATION FACTOR FOR ECCENTRICALLY BRACED FRAMES – ID 692

*D. Ozhendekci, Yildiz Tech. Unv., Turkey*
*N. Ozhendekci, Yildiz Tech. Unv., Turkey*
*A. Z. Ozturk, Yildiz Tech. Unv., Turkey*

Today, conventional static elastic analysis procedures still remain the basis of earthquake resistant design practice. In an elastic analysis procedure, elastic base shear which is the function of code based design spectral acceleration is reduced by the seismic response modification factor (R) considering the inelastic structural behavior. However, "there is no technical basis for the values assigned to the R" and it is "empirical". Most of the studies regarding the R factor combine the results of inelastic time history analyses of SDOF systems with the results of pushover analysis of MDOF buildings. In this paper the inelastic time history analyses of MDOF buildings are used directly in the evaluation of R factor. These analyses are performed for each eccentrically-braced-frame with DRAIN-2DX program for 147 earthquake records of Southern California. Two frames, (3,6-stories) are designed according to LRFD Specification(1999) and AISC Seismic Provisions(2002). The loads and load combinations are determined with respect to IBC(2003). Equivalent lateral load procedure is used for earthquake resistant design. The example frames are assumed to be in Southern California Region and the local site class is chosen as D. Selection of link length during design process ensures that under seismic loads the shear yielding dominates the inelastic response of each link. Ramadan and Ghobarah's inelastic shear-link-element model is used. Each earthquake record is scaled in the inelastic time history analyses in order that the frames reach the deformation limit given in AISC Seismic Provisions. The R factor values are calculated by using these scaled records. It is found that there is a high variation in the values of R factors with respect to record selection although these records are classified with respect to distance, magnitude and frequency content (e.g.,a/v ratio). The median and standard deviation values are also given.

### INCLUSION OF P-DELTA EFFECT IN DISPLACEMENT-BASED SEISMIC DESIGN OF STEEL MOMENT RESISTING FRAMES – ID 1091

*A. Asimakopoulos, University of Patras, Greece*
*D. Karabalis, University of Patras, Greece*
*D. Beskos, University of Patras, Greece*

A procedure for treating the P-Delta effect in the direct displacement-based seismic design of non deteriorating regular steel moment resisting frames is proposed. A simple formula for the yield displacement amplification factor as a function of ductility and the stability coefficient is derived on the basis of the seismic response of an inelastic single degree of freedom system taking into account the P-Delta effect. Extensive parametric seismic inelastic analyses of plane steel frames result in a simple formula for the dynamic stability coefficient as a function of the number of bays and stories of a frame as well as the column to beam stiffness ratio. Stability coefficients based on the inelastic response of the moment resisting frames are considered. Thus, the P-Delta effect can be easily taken into account in a displacement-based seismic design through the stability coefficient and the yield displacement amplification factor. The proposed procedure is compared to the Theta coefficient calculation method included in current seismic codes through simple design examples where both the force-based and the direct displacement-based design methods are implemented.

## ES 5-I: Existing Structures and Earthquake Risk Reduction

Monday 15:30 - 17:00 – Room 21

### PROBABILISTIC SEISMIC ASSESSMENT OF EXISTING R.C. FRAMES – ID 637

*G. Rizzano, Depart. of Civil Engineering-University of Salerno, Italy*
*I. Tolone, Depart. of Civil Engineering-University of Salerno, Italy*

Recent earthquakes have shown that research in earthquake engineering has to be focused on the assessment of vulnerability of existing constructions lacking appropriate seismic resisting characteristics. In fact, older buildings, designed and constructed until the late 1970's, without considering earthquake provisions, constitute a significant hazard in many cities of southern Europe. Therefore, the retrofit should be made in order to reduce the vulnerability, and, as a consequence, the risk to currently accepted levels. To this scope, the scientific community is developing more accurate methodologies in order to evaluate seismic performances of existing structures. In this context, the present paper aims at the evaluation of the Mean Annual Frequency of exceeding a limit state of existing concrete frame by means of the probabilistic approach, introduced by Jalayer & Cornell, accounting for the uncertainty involved in the seismic response of structures. This procedure properly combines the Probabilistic Seismic Hazard Analysis with Probabilistic Seismic Demand Analysis and, finally, with Probabilistic Seismic Capacity Analysis. In order to evaluate the seismic reliability of existing structures taking into account both randomness uncertainty, due to the natural variability, and epistemic uncertainty, due to the degree of accuracy in the modelling of the physical behaviour, in this paper reference is made to experimental results derived from technical literature. In particular, two full-scale frames (bare frame, frame with brick infilled walls) tested pseudo-dynamically at the ELSA Laboratory of Ispra are considered. Starting from the experimental results, the parameters governing the structural model have been calibrated in order to minimize the scatter between the experimental response, in terms of ISDA, and that analytical one and, therefore, to determine the epistemic uncertainty. The developed analysis allowed to evaluate the seismic reliability of the bare frame, the influence of the infill panels and, finally, the reliability of the retrofitting solution with shotcrete.

### PUSHOVER ANALYSES OF FRP RETROFITTED RC FRAMES – ID 862

*B. Ferracuti, University of Bologna, Italy*
*M. Savoia, University of Bologna, Italy*
*R. Pinho, University of Pavia, Italy*
*R. Francia, University of Bologna, Italy*

One of the most interesting applications of composites in civil engineering is retrofitting of RC structures in seismic areas. Plastic hinge confinement by FRP-wrapping enables the development of large displacements and chord rotation ductility factors, as many experimental studies confirmed: due to the high confinement action, concrete may reach large strain before failure, which typically occurs due to FRP rupture. For the numerical modelling of reinforced structures, the effect of confinement for column sections subject to axial load and flexure must be evaluated. In this case, confinement is variable over the cross-section. Even though interesting experimental studies can be found in the literature on full-scale specimens, few numerical models have been proposed. In the present study, constitutive laws appropriate for FRP confinement are implemented in a fibre finite element code (OpenSees): since behaviour of composite material is indefinitely elastic, action exerted on concrete is different from that of concrete confined by steel stirrups, both under loading and unloading conditions. Adaptive and non-adaptive pushover analyses of non-seismically designed RC frames, some of which exhibiting mid-height soft-storey failure mechanisms, have been carried out. It is shown that, in some cases, different pushover methods may predict different failure mechanisms; comparison with dynamic analysis enables the identification of the most reliable solution, typically displacement-based adaptive pushover. Two different retrofitting strategies are proposed and modelled: FRP wrapping of columns of the soft-floor only (local intervention) or FRP retrofitting of all columns of the structure (global intervention). The former is shown to lead to optimum results.

### FRAGILITY BASED ASSESSMENT OF THE STRUCTURAL DEFICIENCIES IN TURKISH RC FRAME STRUCTURES – ID 593

*B. O. Ay, METU, Turkey*
*M. A. Erberik, METU, Turkey*
*S. Akkar, METU, Turkey*

The investigation of structural vulnerability by considering the country-specific characteristics of building stock is vital to manage the earthquake risk and to develop strategies for disaster mitigation. Such a study aimed to assess the structural deficiencies in reinforced concrete frame structures in Turkey is presented in this paper. In a variety of characteristics, low and mid-rise structures, which constitute approximately 75% of the total building stock in Turkey, were focused for the current fragility-based assessment. The seismic design of three, five, seven and nine story reinforced concrete frame structures were carried out according to the current earthquake codes and two dimensional analytical models were constructed accordingly. The uncertainty in material variability is taken into account in the formation of structural simulations. The frame structures in this study are categorized as poor or superior according to the specific characteristics of construction practice and the observed seismic performance after major earthquakes in Turkey. The response statistics in terms of drift ratio were obtained for different sets of ground motion records. After the determination of damage limit states, the fragility curves are generated for each building class. The results are promising in the sense that the inherent structural deficiencies were reflected on the final fragility functions. As a result, this paper provides a reliable fragility-based database for earthquake damage and loss estimation of reinforced concrete building stock in urban areas of Turkey.

### PREDICTION OF ULTIMATE ENERGY DISSIPATION CAPACITY OF EXISTING RC WAFFLE-FLAT-PLATE STRUCTURES – ID 525

*A. Benavent-Climent, University of Granada, Spain*
*A. Catalan, University of Oviedo, Spain*
*X. Cahis, University of Girona, Spain*

Reinforced concrete waffle-flat-plate structures have been used extensively in moderate seismicity areas such the southern part of Spain. Past research showed that this type of structures have low energy-dissipation capacity and high lateral flexibility. Moreover, many of these structures were designed according to old seismic codes, which required relatively low lateral strength and ductility as compared to current codes. Their safety in case of a major earthquake is a matter of big concern. Evaluating their ultimate earthquake resistance is an important issue for deciding whether and to which extent they need to be seismic upgraded.

This paper is the last part of a more extensive research presented by the authors in two companion papers (PART I and PART II), which aims at evaluating the ultimate seismic resistance of existing reinforced concrete waffle-flat-plate structures constructed in the southern part of Spain before 1994, according to the old seismic code PDS-74. The ultimate seismic resistance is estimated in terms of ultimate energy absorption/dissipation capacity (UEDC). This paper discusses the results of the pushover analyses and the nonlinear dynamic response analyses presented in companion papers (PART I and PART II respectively), and based on these results, a simple formulation for predicting the UEDC of this type of structures is proposed. The formulation is based on the Housner-Akiyama energy approach.

### A PROBABILISTIC PERFORMANCE EVALUATION OF AN ASYMMETRIC REINFORCED CONCRETE FRAME (SPEAR) BUILDING – ID 1388

*M. Dolsek, University of Ljubljana, Slovenia*
*P. Fajfar, University of Ljubljana, Slovenia*

An important goal of performance-based earthquake engineering is the prediction of the mean annual probabilities of exceedance of a given performance level (limit state). One of the methods, which is realizing this goal, is the SAC-FEMA method developed as a part of broader probabilistic framework adopted at PEER center. The SAC-FEMA method involves the so-called Incremental Dynamic Analysis which represents the relation between the engineering demand parameter and the seismic intensity measure. As an alternative to Incremental Dynamic Analysis, a simplified approach, called IN2 (incremental N2 analysis), has been proposed. The IN2 can be, in combination with predetermined data on dispersion typical for a specific structural system, employed in the PEER probabilistic framework. Using this simplified approach, the computational efforts can be substantially reduced.

In the paper, the IN2 analysis is summarized. Its application is demonstrated by an example of a three-story plan-asymmetric reinforced concrete frame building. The structure was pseudo-dynamically tested in full-scale in the ELSA laboratory in Ispra within the SPEAR project. The mathematical model, used in analyses, which were performed with OpenSees program, consists of one-component lumped plasticity elements. It has been validated by test results. The probability of exceedance of the near collapse limit state, which is assumed to be met when the near collapse chord rotation is exceeded in the first column, is calculated with the proposed simplified approach and compared with results of a more accurate analysis. The intermediate results, determined by the N2 method, like the summarized IN2 curve, torsional amplification factors and the top displacement corresponding to the near collapse limit state, are also presented in the paper and compared with results obtained by nonlinear dynamic analysis.

### P25 SCORING METHOD FOR DEFINING RAPIDLY THE COLLAPSE VULNERABILITY OF RC STRUCTURES – ID 67

*I. E. Bal, ROSE School, Italy*
*S. Tezcan, Bogazici University, Turkey*
*F. G. Gulay, Istanbul Technical University, Turkey*

With the urgent need for rapid inspection methods to check the present building stock in earthquake prone zones in Turkey, an effective rapid assessment technique called "P25 Scoring Method" has been developed and tested on 26 different case studies recently, in order to predict the collapse vulnerability of the R/C structures. After a short description of the approach, the study presents the sensitivity study of the method to the selected structural parameters by considering incremental deviation of the final scores from the base model. Further, the methodology was performed on additional 100 damaged buildings in order to check the reliability of the method and some necessary modifications have been applied to the algorithm after considering this larger database. The evaluation of the results has been interpreted as a beneficial guidance for local authorities. The risk bands defined according to the final scores and the effect of changing the bandwidth has been studied in an economical manner. A satisfactory correlation of the method with the real damage states is obtained and a ready-to-use methodology has been introduced for future studies.

## ES 5-II: Existing Structures and Earthquake Risk Reduction

Tuesday 10:45 - 12:15 – Room 21

### DEVELOPMENT OF FRAGILITY CURVES FOR UNREINFORCED MASONRY BUILDINGS USING ANALYTICAL METHOD – ID 107

*A. Bakhshi, Sharif Univ. of Technology, Iran (Islamic Republic Of)*
*K. Karimi, Sharif Univ. of Technology, Iran (Islamic Republic Of)*

Fragility curves mainly indicate the vulnerability of structures in earthquakes. These curves correspond to the probability of exceeding a certain state of damage versus one of earthquake intensity parameters. In previous works done in this field, fragility curves are usually plotted based on PGA (Peak Ground Acceleration), even though PGA is not a good estimate for evaluation of damage to structures. Therefore, in this research, CAV (Cumulative Absolute Velocity) has been chosen as earthquake intensity parameter. There are two different methods in obtaining fragility curves: Analytical and Experimental. Analytical method is used in this project. Relatively comprehensive works are done for concrete structures, steel structures and bridges, while limited research is done on Un-Reinforced Masonry (URM) buildings, especially the traditional types which are so vulnerable to earthquakes. Due to abundance of URM in many countries and high seismic activity of some regions where they are built, fragility curves are developed for variety of earthquake characteristics in this paper. Moreover, FEMA 356 and 357 seismic provisions and retrofitting methods are applied to these buildings and fragility curves before and after retrofitting are compared.

### STRUCTURAL BEHAVIOUR OF HISTORIC EARTHEN BUILDINGS: DAMAGE LEVEL AND ECONOMIC RETROFITTING PROPOSALS – ID 1398

*R. Arroyo Matus, Universidad Autonoma de Guerrero, Mexico*
*A. Salgado Rodríguez, Universidad Autonoma de Guerrero, Mexico*

Results of a seismic evaluation of mexican southeastern dwelling houses located at the historic town centers of Taxco de Alarcón, Gro., Oaxaca de Juárez, Oax. y Chiapa de Corzo, Chis., are presented. A seismic hazard evaluation for these three historic town centers, including a seismic microzonification study, is performed. A methodology to estimate structural vulnerability curves for adobe buildings is developed. In order to obtain expected structural damage levels for earthquakes with different return periods, the curve of vulnerability is combined, through a probabilistic procedure, with the seismic hazard at these historic town centers. Finally, a simplified methodology is developed to choose structural retrofitting to minimize seismic damage.

### EXPERIMENTING SEISMIC VULNERABILITY ASSESSMENT AND STRENGTHENING IN A MASONRY VILLAGE – ID 1429

*M. A. Parisi, Politecnico di Milano, Italy*
*C. Chesi, Politecnico di Milano, Italy*

For historical town centers and villages that are mostly constructed with masonry buildings, the major steps in seismic risk mitigation consist of assessing the vulnerability level of the buildings and developing strengthening projects that are effective and feasible. In the last decades, much research work and experience has been devoted to both these issues. Yet, full scale experimetation on real situations would help reduce many remaining uncertainties in the methods. In the assessment of vulnerability, for instance, the effect of buildings in partial continuity with the one examined is still being studied, and the effect of ground sloping is often considered only grossly. A general difficulty in the studies is even in the collection of real data for subsequent analyses. A stone masonry village in southern Italy was abandoned two decades ago because of an estimated high earthquake risk. Costs for its strengthening

and uncertainties in results were considered too high at the time. The complex, guarderd but not inhabited, has been now made accessible, within a research program, for study purposes, also in view of a possible rehabilitation. At the moment, however, the village offers an exceptional opportunity as an open-air lab for experimenting in-situ studies and techniques, ranging from the analysis of masonry on full-size cases to the detailed study of vulnerability of a typical stone masonry village, and to the identification of the strengthening interventions most effective in reducing the assessed vulnerability. First results of vulnerability assessment have been obtained for most buildings and are now being deepened with considerations of continuity and grading. Detailed information on the mechanical properties on the local masonry is being obtained from experimentation in situ, carried out also with flat jacks. The work proposed here will present the various aspects and results of the research program.

### THE USE OF PASSIVE SEISMIC PROTECTION IN OLD MASONRY BUILDINGS – ID 1065

*L. Guerreiro, IST-DECivil, Portugal*
*M. Branco, Portugal*

In the recent years many technologies of seismic protection had been developed in attempts to mitigate the effects of earthquakes on old masonry buildings. The most important examples of seismic protection technology are the base isolation or the use of energy dissipators and there are already an important number of examples of the use of these technologies in seismic rehabilitation all over the world. In this paper a study for the rehabilitation of an old masonry building with the use of seismic passive protection is presented. The building object of the study is an example of an important part of the existing building stock of Lisbon, commonly designated by "Gaioleiros". This type of building were constructed in the period comprised between the end of the XIX century and the start of the XX century, and are composed by exterior masonry walls with wood infill panels and wooden floors. This kind of structures is particularly vulnerable to the seismic action and is object of different studies for possible retrofit interventions. In the study three different solutions were compared: the use of viscous dampers; the use of base isolation and a more traditional intervention with reinforced concrete walls.

### MULTI-LEVEL PROCEDURE FOR THE SEISMIC VULNERABILITY ASSESSMENT OF MASONRY BUILDINGS – ID 171

*S. Cattari, University of Genoa, Italy*
*S. Frumento, University of Genoa, Italy*
*S. Lagomarsino, University of Genoa, Italy*
*S. Resemini, University of Genoa, Italy*

After Molise earthquake (2002 Southern Italy), the problem of the public-facilities seismic vulnerability was strongly underlined. Recent Italian regulations established that seismic-safety checks have to be developed on strategic public buildings (schools, etc.) in five years. A large part of this stock is made of masonry buildings. Aiming to assess the seismic risk for these structures, the need of a vulnerability model feasible for the analyses at the territorial scale arises. Once evaluated the main concern for the risk-mitigation strategy, a detailed study is valuable to account for the structural peculiarities. A multi-level procedure for the seismic safety evaluation of masonry buildings is proposed, focusing on the case of the school buildings of Sanremo (North-western Italy). The methodology involves different approaches: 1) macroseismic vulnerability model (Giovinazzi et al. 2004); 2) simplified mechanical models (Dolce et al. 2004, Guidelines 2005); 3) detailed models (based on the macroelement schematization, Galasco et al. 2004). The methodology may be applied using differently detailed data and the vulnerability level is achieved through different, but correlated, parameters: the vulnerability indicator, based on typological and observational data (macroseismic model), the PGA value related to the structural collapse (mechanical models), the expected performance level in terms of displacement (detailed model). The results comparison for the school buildings in Sanremo highlights limitations and peculiarities of the analysed models. Subjects of particular interest are the different collapse mechanisms (soft storey or uniform) assumed in the mechanical models and the procedure to take into account the irregularity factors, strongly affecting the dynamic response, e.g. inducing torsional effects and anomalous force redistribution. The detailed macroelement model of the most significant buildings allow us to examine with more accuracy these topics, performing non-linear analyses (in which the force redistribution directly derives from the damage pattern evolution), as in Eurocode 8 and Italian seismic decree (OPCM no.3431 2005).

### SEISMIC ANALYSIS OF A URBAN BLOCK IN FAIAL ISLAND - AZORES – ID 384

*N. Neves, Faculty of Engineering of University of Porto, Portugal*
*A. Arêde, Faculty of Engineering of University of Porto, Portugal*
*A. Costa, Faculty of Engineering of University of Porto, Portugal*

The paper deals with numerical seismic analysis of an urban building block located in Faial island, Azores, hit by an earthquake on July, 9th 1998. It includes two different construction types with distinct dynamic behaviours, mostly traditional masonry structure on two-three storey buildings and a reinforced concrete structure building in one block side. The analysis was supported by in-situ and laboratory tests carried-out during this and previous works. An experimental campaign was performed with ambient vibration tests on three traditional houses and on the RC building. Mode shapes and vibration frequencies were obtained allowing for the calibration of mechanical parameters considered in numerical models (Neves, N. 2004). Time–domain dynamic analyses were made using the accelerograms recorded during the earthquake. A first analysis stage was limited to three houses in order to assess the influence of group effect and floor stiffness on response parameters. The second stage, described in this paper, deals with the seismic analysis of the global block behaviour, to assess the effect of: the RC building, the floor characteristics and the possible reinforcing solutions in some buildings. The most vulnerable block zones and their interaction with remaining structures, were also identified. The study was done adopting a global finite element model, discretizing each individual building with shell elements and material properties calibrated in a previous study. Several modelling variants were considered to study the influence of abovementioned issues. When possible reinforcing schemes were considered, results allowed assessing their efficiency on improving the block behaviour. Interdependency between different block elements was also evidenced, showing that reinforcing may be done by means of single interventions in localized zones. However, stress redistributions caused by interventions must be taken into account because stiffness variations may increase stresses in reinforced zones, which means that individual building might not be appropriate.

## ES 5-III: Existing Structures and Earthquake Risk Reduction

Tuesday 13:30 - 15:00 – Room 21

### THE TURKISH SEISMIC REHABILITATION CODE – ID 318

*H. Sucuoglu, METU, Turkey*

In association with the urban risk mitigation efforts in Turkey, a seismic rehabilitation code has been developed during 2003-2005 by an appointed committee. This code, entitled "Assessment and Strengthening of Existing Buildings" is appended to the Turkish Seismic Code as its Chapter 13, and had been effective legally by 2006.

Chapter 13 of the 2006 Turkish Seismic Code sets standards for the collection of field data in its first part. The existing material strengths are based on statistical evaluation of field data, with no further reduction by safety factors. Linear elastic and nonlinear static

procedures are proposed for structural evaluation. A performance-based evaluation methodology is used under three levels of earthquake ground motion intensities having the probabilities of exceeding 50, 10 and 2 percent in 50 years. The performance acceptance criteria are based on demand to capacity ratios at critical sections for the linear procedures, and material strains for the nonlinear procedures. Member performance limits are described for minimum damage, life safety and significant damage levels, considering the anticipated failure mode and ductility capacity of each member. Structural performance is then calculated by accounting for the distribution of member damages over the building. Column and wall performance dominate the system performance compared to the beams.

Retrofit techniques are also proposed in Chapter 13 for reinforced concrete structures. They consist of detailing requirements for concentric and eccentric added shear walls, column and beam jacketing for strength and ductility enhancement, and strengthening of masonry infill walls by adding new material layers.

Chapter 13 of the Turkish Code and Part 3 of Eurocode 8 essentially follow similar approaches for seismic rehabilitation. The basic differences in Chapter 13 are less restriction for linear elastic procedures, and the assembling of member performances for obtaining a global system performance level.

## EVALUATION OF THE DUCTILITY AND STRENGTH DEMANDS FOR THE EXISTING BUILDINGS IN TURKEY – ID 280

*P. Gundes Bakir, Katholieke Universiteit Leuven, Belgium*
*G. Degrande, Katholieke Universiteit Leuven, Belgium*
*G. De Roeck, Katholieke Universiteit Leuven, Belgium*

This study investigates the seismic demands on existing structures due to the catastrophic 1999 Mw= 7.1 Duzce earthquake. It has long been argued that the seismic damage induced in existing buildings in Turkey during the 1999 Kocaeli and Duzce earthquakes was due to the poor construction practices in Turkey. The aim of this study is not to argue these allegations but broaden this discussion and show that high seismic demands on existing buildings may have contributed to the observed damage during these earthquakes. A comprehensive review of the inelastic response of the existing buildings, in terms of seismic demands is made. This study shows that the ductility demands of the Duzce earthquake were very severe (well above the code prescribed values), even for moderately inelastic structures, and were not correlated to the epicentral distance. Substantial damage should be expected at all districts of Istanbul in future earthquakes, especially at Atakoy, which showed very high ductility demands in both the NS and EW directions. For elastic structures within the acceleration and displacement sensitive regions of the spectrum and for inelastic structures, viscous dampers have little or no beneficial influence. However, base isolation may substantially improve the performance of a structure in the inelastic domain by decreasing the yield strength demand, although it may not be beneficial in the elastic domain. The ductility demands of the Duzce earthquake are compared with the ductility demands from the most significant earthquakes in Italy, Portugal and former Yugoslavia in the last 30 years. It is apparent that the ductility demands were much higher in the Duzce earthquake compared to these earthquakes.

## RISK-BASED SAFETY EVALUATION OF EXISTING BUILDINGS - THE CONCEPT OF THE SWISS TECHNICAL NOTE SIA 2018 – ID 639

*E. Kölz, Risk&Safety AG, Switzerland*
*T. Vogel, ETH Zurich, Switzerland*
*B. Duvernay, Federal Office for the Environment, Switzerland*

Over the past few decades codified earthquake actions were increased considerably in Switzerland. As a consequence, older structures often do not comply with actual code requirements. Such structures might be judged unsafe and considered for upgrading. This however is very costly and upgrading all the existing building stock to meet actual code requirements would leave us bankrupt. For this reason the Swiss Society of Engineers and Architects (SIA) charged an expert group to work out a technical note for an appropriate evaluation of the earthquake safety of existing buildings. The result of this work is quite innovative: the decision of whether a structure might be considered safe, or whether upgrading measures must be taken, is based on risk criteria. A so-called compliance factor plays a predominant role. For the existing structure under consideration the compliance factor describes the degree of fulfilment of the actual code requirements. A compliance factor which is lower than unity means that the code requirements are only partially fulfilled. If it lies below a certain minimal threshold, the reasonableness of possible measures must be evaluated. If it lies above the minimal threshold but below unity, the commensurability of possible measures must be evaluated. In this evaluation, life-saving costs, i.e. the ratio of safety costs over risk reduction of the measures, must be determined and checked whether they lie below or above fixed threshold values. In case commensurable and reasonable measures cannot be found, no measures are necessary. The technical note put into force at the end of 2004 has now undergone one year of practical experience. The acceptance of the note was positive. However, also some difficulties in applying the note have been observed and a number of reactions of building owners have been received. Both are subject of discussions in view of improving the note.

## SEISMIC EVALUATION OF A COMMERCIAL BUILDING ACCORDING TO SIA 2018 USING A DISPLACEMENT-BASED ASSESSMENT – ID 327

*K. Pfyl-Lang, Basler & Hofmann, Switzerland*
*P. Zwicky, Basler & Hofmann, Switzerland*
*G. Kerland, Swiss Reinsurance Company, formerly Basler & H, Switzerland*

The majority of the building stock in Switzerland was built without earthquake resistant design. There-fore the earthquake protection is often insufficient, as the buildings do not comply with modern seismic standards. As it is not possible to upgrade all existing structures to the current standard, the question arises as to which safety-demand existing buildings should comply and hence which upgrading strate-gies are commensurable. The technical bulletin SIA 2018, introduced in Switzerland in 2004, gives guidance for the evaluation of the seismic resistance of existing buildings. This includes technical guidance on the displacement-based assessment, as well as risk and cost considerations for the deci-sion-making process. This paper presents the application of the technical bulletin SIA 2018 to a typical commercial building in Switzerland. The seismic evaluation took place in line with the intended refurbishment of the build-ing, which facilitates possible seismic upgrading as well as reducing the effective cost. The building is a typical eight-story reinforced concrete wall structure. Using a displacement-based approach, the capacity curve of the building is calculated and compared to the displacement demand, defined by the current Swiss Standard. The comparison shows that the building achieves only 60% of the required safety-demand of new structures. Therefore, an appropriate upgrading strategy is pro-posed and its commensurability evaluated, by comparing its cost with the risk reduction to be attained.

## SEISMIC EVALUATION OF EXISTING BUILDINGS: LESSONS LEARNT WITH THE NEW SWISS BUILDING CODE ANNEX SIA 2018 – ID 780

*B. Duvernay, Federal Office for the Environment, Switzerland*
*E. Kölz, Risk&Safety AG, Switzerland*
*R. Vogt, ACS Partners AG, Switzerland*
*X. Mittaz, SD Ingénierie SA, Switzerland*

In 2004, a group of experts elaborated an annex to the Swiss building codes in order to cover the problem of the seismic verification of existing buildings. This annex sets minimal seismic safety requirements for existing buildings and proposes cost benefit criteria for their eventual retrofit.

The first central concept is the compliance factor which indicates the degree of compliance of an existing building compared to the requirements for new buildings. Below a minimal threshold value of the compliance factor, the safety of individuals is unacceptable

with an annual probability of death exceeding 1/100'000. Above this threshold, the safety of individuals is judged acceptable.

The second central concept is the so called life-saving costs, which describes the cost effectiveness of retrofit measures in terms of money invested versus lives saved. Two cases are distinguished. If the compliance factor is below the threshold value, retrofit measures are in principle mandatory, but their associated life-saving costs should not exceed 100 mio CHF per life saved in order to bring the building to the minimal safety level (reasonableness criterion). If the compliance factor is above the threshold, measures should be implemented for life-saving costs not exceeding 10 mio CHF per life saved (commensurability criterion).

Most seismic verifications using SIA 2018 are linked to transformation or retrofit projects. On the basis of collected evaluation reports, this paper analyses how the concepts of SIA 2018 were understood and applied in practice. A strong focus is set on the application of the cost benefit criteria and the resulting intervention recommendations as well as on the degree of refinement of the structural analysis. This study will serve as a reference for the planned revision of the SIA 2018, which has to be revised every 3 years.

### EAEE-TG3 REPORT - VULNERABILITY AND SEISMIC RISK OF INDIVIDUAL STRUCTURES: A STATE OF PRACTICE – ID 1490

*M. Dolce, University of Basilicata, Italy*

Recent earthquakes all over the world remind us that most of schools, hospitals and facilities, which play fundamental roles for Civil Protection or hosting high value social and economical content are highly vulnerable to earthquakes. A strong need for their vulnerability and risk assessment is now evident. Due to their awful number and the need of focusing on individual rather than class of structures and infrastructures, new methods for vulnerability assessment are required, that operate at a definition level higher than current methods for dwelling buildings. In the meanwhile, modelling and analysing methods, such as the ones required by seismic regulations, cannot be used to evaluate all the structures of public interest, at least in a first evaluation phase. The objective of Task Group 3 has, therefore, been re-addressed towards problems of structural vulnerability assessment of individual structures and of seismic hazard evaluation and local effect prediction in individual sites. Special attention has been devoted to methods and procedure that, though implying in situ inspections, tests and measurements, do not require large amount of money, take account of all structural (and non structural) features affecting the actual seismic behaviour of a structure and all the important hazard and amplification parameters affecting the shaking intensity and frequency content, use simplified up-to-date models, provide a satisfactory level of damage prediction for different earthquake intensities. A state of practice on the above problems and procedures has been carried out by TG3. A questionnaire has been sent to the European researchers potentially dealing with the different procedures applied in Europe. The attention has been focused on procedures that have been actually applied, not just research proposals. The paper summarises the results of the enquiry and provides general information of the actual trend in Europe.

## ES 5-IV: Existing Structures and Earthquake Risk Reduction

Tuesday 15:30 - 17:00 – Room 21

### VULNERABILITY ASSESSMENT OF TRADITIONAL BUILDINGS IN COIMBRA, PORTUGAL, SUPPORTED BY A GIS TOOL – ID 1146

*R. Vicente, University of Aveiro, Portugal*
*H. Varum, University of Aveiro, Portugal*
*J. A. Mendes Da Silva, University of Coimbra, Portugal*

The increasing concern and consequent appraisal on durability, conservation state and change of use of old buildings in urban centres is greatly related with structural safety assessment, particularly to seismic actions. It is largely recognised that the seismic vulnerability of the majority of historical city centres, with buildings without adequate seismic capacity, is high. The need to catalogue buildings according to their seismic vulnerability, particularly traditional buildings, is a key issue in any renewal or rehabilitation process. Recently, different methods for seismic vulnerability assessment have been proposed, with different levels of detail. Research carried out on seismic vulnerability have underlined that the performance of traditional buildings under earthquake actions is governed by several structural features, some of which can be peculiar of each urban context and construction technology. Seismic vulnerability assessment extended to whole historic centres has outlined the importance of GIS mapping applications in order to aid in the intervention and risk management plans. The need for an integrated multi-purpose tool, connected with a GIS, as well as with a relational database, in order to have a deeper and interdisciplinary knowledge of the site and hence to be able to create a modular approach and manage the historical building stock, conservation works, retrofitting strategy, risk assessment, building characteristics and vulnerability, damage and cost estimation is essential. In this paper, it is presented and discussed the strategy and methodology adopted for the vulnerability assessment of the city centre of Coimbra, in Portugal, through the GIS mapping of the building stock of the project perimeter. Development of vulnerability studies in urban centres can be conducted aiming to identify building fragilities and reduce the seismic risk.

### SEISMIC RISK ANALYSIS OF R.C. BUILDING CLASSES AT THE URBAN SCALE – ID 567

*I. Iervolino, University of Naples Federico II, Italy*
*G. Fabbrocino, Department SAVA-University of Molise, Italy*
*G. Manfredi, University of Naples Federico II, Italy*
*M. Polese, University of Naples Federico II, Italy*
*G. M. Verderame, University of Naples Federico II, Italy*

Seismic risk assessment at urban scale may be defined as estimation of number of buildings expected to reach a given limit state in the region and time period of interest. It is related to the failure probability of a homogeneous class of buildings and its characterization. This definition introduces new issues in respect of reliability analysis for single structures which, under some conditions, has been already addressed in close form. Mechanical approach may be suitable in respect of the requirements of such territorial evaluation, thus appropriate limit state functions have to be developed to get the failure probability of classes belonging to the building stock. Non-linear seismic capacity, in terms of base shear and/or displacement, has to be expressed as function of those structural parameters which identify single structures within the class. The latter may be carried out by multiple regression analysis. Distributions of random variables affecting capacity are estimated by sampling the territorial population. In a displacement-based approach inelastic seismic demand may refer to probabilistic seismic hazard analysis at the site and suitable displacement modification factors. All these issues are discussed in the paper; moreover, an explanatory application to R.C. structure classes is presented.

### EFFECT OF INITIAL-PHASE SEISMIC ASSESSMENT PARAMETERS OF EXISTING BUILDINGS ON STRUCTURAL BEHAVIOR – ID 173

*M. Inel, Pamukkale University, Turkey*

In the last decades, industrialization and rapid population growth has brought an urgent need for new accommodation supply. Many buildings were constructed as quickly as possible regardless of any care for quality and safety considerations. Economic losses and casualties during recent earthquakes have increased interest on research related to seismic vulnerability assessment of existing buildings in many countries, especially in earthquake prone regions. The number of buildings that should be checked directs the civil engineering profession to find easy and quick methods

to identify the safety level of structures. Several procedures have been proposed to predict seismic vulnerability of existing buildings (FEMA 154, FEMA 310, and Japan Seismic Index). The seismic vulnerability assessment procedures can generally be classified into three stages: walk-down, preliminary, and final evaluation stages. The walk-down and preliminary evaluation stages are most widely used procedures when quick assessment of huge number of buildings is point of interest. In these stages, typical parameters considered for vulnerability assessment include site classification, number of stories, existence of soft story, short columns, and heavy overhangs, potential pounding possibility, and lateral load resistance of the building. This study aims to examine the effects of these parameters on seismic response of reinforced concrete buildings through an analytical study using nonlinear static procedures. The scope of current study is limited to low- and mid-rise reinforced concrete buildings because the high-rise buildings require specific and detailed evaluation rather than the use of conventional seismic vulnerability assessment procedures. The implications are discussed in the paper.

### HAZARD CONSISTENT ANALYTICAL FORMULATION FOR SEISMIC LIMIT-STATE PROBABILITIES – ID 987

*X. Romão, FEUP, Portugal*
*J. Guedes, FEUP, Portugal*
*A. Costa, UA, Portugal*
*R. Delgado, FEUP, Portugal*

Probabilistic seismic assessment requires extensive computational effort resulting from variability in input ground motions and material properties. Nonetheless, such methodologies are of considerable importance, namely for pre-earthquake disaster planning or development of retrofitting programs. The proposed paper presents a general framework for the analytical definition of closed form expressions for the hazard consistent probability of exceedance of a given Limit-State (LS) defined by a structural response parameter. The LSs are defined by single deterministic thresholds of structural response quantities. Existing work on seismic LS probabilities focuses essentially on the derivation of fragility curves. Though this approach yields important structure specific results, they may not be sufficient for practical use on cost/effectiveness decision-making processes if the earthquake hazard (probability of exceedance) information is not included. The proposed methodology treats seismic LS probabilities with direct inclusion of ground motion hazard, thus yielding an integrated structure/site specific risk result, better suited for cost/effectiveness decisions. The methodology is summarized in the following. First an Extreme Type probabilistic distribution is fitted to the site's ground motion hazard curve. Nonlinear dynamic analyses are then performed to determine the structure's peak structural response to a set of appropriate accelerograms and structural demand parameters are recorded. Then, for each analysis, a mathematical expression is fitted to the evolution of the chosen structural demand for increasing values of the ground motion intensity measure. Finally, the probabilistic distribution of the ground motion hazard is analytically transformed into the curve giving the probability of exceedance of the chosen response quantity. Different approaches will be proposed to account for the randomness of material properties and ground motion input within the present framework. The paper will present an application of the assessment of different LS probabilities of a reinforced concrete building.

### EFFICIENT EARTHQUAKE VULNERABILITY AND DAMAGE ASSESSMENT OF LARGE GROUPS OF EXISTING RESIDENTIAL BUILDINGS – ID 1118

*Y. Offir, NBRI-Technion, Israel*
*D. Yankelevsky, NBRI-Technion, Israel*

This paper presents a new methodology for earthquake vulnerability assessment of a large inventory of existing buildings. It is of major importance for residential areas in earthquake prone areas where a considerable seismic risk exist. There is a need for rapid, cost effective and reliable assessment of the capacities of the existing buildings and to forecast the damages that may develop as a result of a given earthquake scenario. This is essential for rational planning of many actions, such as the retrofit programs of existing buildings before the occurrence of a strong earthquake, allocation of rescue forces and equipment to optimally deal with the forecasted damage, short term and long-term rehabilitation planning after the occurrence of a strong earthquake, etc. The present methodology is dealing with residential buildings and can be extended to other types of buildings. The proposed approach is based on a very limited amount of available data in a common GIS database. The additional needed data is derived from thorough examination of the topology of the layout of the buildings together with supporting data related to local historical development, applicable codes and regulations, etc. With this set of data, a most likely structural system is composed, and it is analyzed in a special approximate non-linear manner, suitable to the uncertainty conditions of the input data. When the capacity and the demand are determined, the expected damage may be estimated for the entire inventory of these buildings. The algorithms are integrated in a GIS database to enable examination of a large inventory of buildings. All the algorithms are developed in modular packages that can be modified or combined according to various given sets of data, and can be used as "automatic" algorithms in special purpose software. The paper will present the methodology and provide examples of its implementation.

### SEISMIC SAFETY ASSESS OF NUCLEAR FACILITY STRUCTURES USING RISK MITIGATION FACTORS – ID 1227

*T. Aoki, Aichi Institute of Technology, Japan*
*B. Stojadinovic, University of California, Berkeley, United States*
*Y. Arici, Bechtel Corp., United States*

Seismic safety of new nuclear facility structures in the US is evaluated using the risk reduction factor, a ratio of the probability of hazard to the probability of failure. This ratio informs the designer on how the properties of the structure reduce the risk of failure in a given seismic hazard environment. This approach has been developed by Kennedy and Short in 1980's and has been recently adopted in the ASCE 43-05 document.

In this paper we are proposing a risk mitigation factor to assess the seismic safety of existing nuclear facilities. Risk mitigation factor is the risk reduction factor applied to existing structures. Thus, we demonstrate how to use the fragility information available in the literature to compute the probability of failure given a seismic hazard environment. Furthermore, we investigate the formulation of risk mitigation acceptance criteria at the structure level (as is traditionally done for nuclear structures) and at the component level (as is traditionally done for conventional structures) and compare the two approaches. We conclude with an example of using the risk mitigation factor to assess the seismic safety of the CAMUS I shear wall benchmark structure.

## ES 6: Lifeline Systems

Friday 10:45 - 12:15 – Room 21

### THE SEISMIC SCENARIO SIMULATION OF ELECTRIC POWER SYSTEMS – ID 200

*G. Y. Liu, National Center for Research on Earthquake Eng., Taiwan*
*Y. J. Wang, Dep. Electrical Eng., National Taiwan University, Taiwan*
*C. W. Liu, Dep. Electrical Eng., National Taiwan University, Taiwan*

Catastrophic earthquakes may cause severe power outages and, as a consequence, induce huge direct and indirect losses and raise difficulties in emergency management. It is highly desirable to be facilitated with a scenario simulation tool which can estimate the likely power outage, according to which adequate measures could be

taken to ensure the preparedness. In order to answer this challenge, hazard-induced power outages were firstly analyzed in this study and split in two phases temporally. Phase one refers to the real-time response of the system to its damage, in which the consequence of power imbalance and the activation of relay protection should be considered. Phase two refers to a while after the earthquake when system operators start restoring the power supply. How much it can be restored depends on how badly it is damaged as well as how repair work proceeds. Secondly, analysis procedures for estimating the two phases of power outage were developed, respectively. This was done by partly re-organizing the power network which isolates the damaged or abnormal nodes and lines, and partly conducting power flow analysis which mimics the response of system operators. The power system in Taiwan was then carefully treated as a case study. Regional line-source earthquake scenarios were introduced to have a better prediction of ground motion intensities. High voltage transformers in its critical substations were assumed vulnerable. A large amount of computational work has been carried out to obtain its seismic performance through Monte Carlo simulation. Seismic source grids which contribute most to the risk of power reduction have been identified. The consequence of power disruption caused by regional earthquakes of highest potential has been examined in detail. All these will provide useful information to utility owners as well as emergency managers.

### EVALUATION OF FUNCTIONAL PERFORMANCE OF COMPLEX NETWORKS FOR CRITICAL INFRASTRUCTURE PROTECTION – ID 413

*N. Nojima, Gifu University, Japan*

Protection of critical infrastructure from hazardous events is an issue of high priority in modern society. Recent natural and manmade disasters demonstrated that catastrophic consequences were induced by functional disruption of urban infrastructure comprised of complex network systems. Such events motivated national/local governments and private sectors to make efforts on critical infrastructure protection. In particular, much attention has been paid to catastrophic damage spread in major earthquakes, because those events were characterized by simultaneous occurrence of intensive damage to urban infrastructures. With this background, this study presents a method for evaluating functional performance of complex network systems toward the goal of effective protection of critical infrastructure. Conventional studies on lifeline system performance provide fundamental concepts for operation of network models under adverse circumstances. Node removal is a typical way to artificially degrade network models, representing the loss of nodal function. Two representative patterns of node removal are compared. One is preferential (or targeted) node removal to examine attack-tolerance of the network. The other is random node removal to examine error-tolerance. In this study, several measures are introduced for evaluating post-disaster performance of degraded networks. They are: 1) relative reachability among all node pairs, 2) number of clusters (disconnected subgraphs), 3) maximum cluster size, 4) number of isolated nodes, 5) average path length among all node pairs, and 6) diameter (the longest path length in the maximum cluster). Numerical examples are presented for 1) artificially generated complex networks, 2) the commercial airline network system in Japan, and 3) road network system damaged by the 2005 Niigataken-Chuetsu earthquake in Japan. The results of performance evaluation are shown in comparative perspective. It has been found that the network performance strongly depends on the node removal patterns, network configurations, and severity of attacks or disasters as well.

### EXACT METHODOLOGY OF FLOW PATH ANALYSIS FOR LIFELINE NETWORK SYSTEMS – ID 466

*M. Bastami, Kobe University, Japan*
*S. Takada, Kobe University, Japan*
*Y. Kuwata, Kobe University, Japan*

Complexity of damage analysis of lifeline networks is main reason to use simple as well as approximate methodologies. Huge amounts of direct and indirect losses due to seismic damage of these vital systems need more effort to develop better methodologies. In this research a new view on damage analysis of networks in general and seismic damage analysis especially is presented. Exact simulation of networks needs a comprehensive methodology based on exact flow path strategy. This important and realistic strategy is pursued in this research. Modified Path Matrix (MPM) methodology is developed based on exact flow path strategy to obtain all possible paths between each desired source as well as desired demand. This method is based on modifying or extension of path matrix (or cut-set matrix) on each level of connectivity. LSAR-Ver1 Software is developed for seismic probabilistic analysis of all lifeline system networks for all seismic hazards, i.e., wave propagation, landslide, liquefaction and fault cross effects. This software supports three methods to probabilistic analysis for components of a lifeline system network. LSAR-Ver1 supports four possible methods for seismic hazard loading of lifeline systems. As case study network of Great Tehran Region Power Supply System is analyzed for different probable earthquake scenarios. Results of analyses show this network of power supply system network is vulnerable for seismic events. Among all components, substations are the most vulnerable and weakest especially substations by rail support system.

### PREDICTION OF EARTHQUAKE DAMAGE TO WATER PIPELINES IN DENIZLI CITY, TURKEY – ID 383

*S. Toprak, Pamukkale University, Turkey*
*F. Taskin, Pamukkale University, Turkey*

During the devastating 1999 M7.4 Kocaeli and M7.2 Duzce, Turkey earthquakes, substantial water supply damage occurred in many cities. For example, the entire water distribution system in Adapazari was damaged. The water service could not be restored until many months after the earthquake. One of the most critical lessons of the recent earthquakes is the need for seismic planning for lifelines, with appropriate supplies and back up systems for emergency repair and restoration. Seismic planning which includes hazard mitigation, risk management and emergency response, however requires physical loss estimations before the earthquakes occur. Earthquake damage to buried pipelines can be attributed to transient ground deformation (TGD) or to permanent ground deformation (PGD) or both. TGD occurs as a result of seismic waves and often stated as wave propagation or ground shaking effect. PGD occurs as a result of surface faulting, liquefaction, landslides, and differential settlement from consolidation of cohesionless soil. The relative magnitudes of TGD and PGD determine which one will have predominant influence on pipeline response. In this study, damage to the water pipelines of Denizli City, Turkey during an earthquake of about M6.3 both from the TGD and PGD such as soil liquefaction were assessed. Denizli is an important industrial and tourism center and also one of the largest cities in the west part of Anatolia. Recent studies show that this region is expected to have an earthquake of about M6.3 in near future. Geographic Information Systems (GIS) were used in the analyses. Recent research results and damage correlations obtained from the water supply performance during the earthquakes in the last decade were incorporated into the assessment. Relative effects of TGD and PGD on the pipeline system were discussed. The post-earthquake performance of the water pipeline system was evaluated and various mitigation strategies were suggested.

### SURFACE GROUND STRAINS FROM DENSE ARRAY WEAK MOTION RECORDS: THE CASE OF PARKWAY VALLEY, NEW ZEALAND – ID 879

*C. Smerzini, Dept. Structural Eng., Politecnico di Milano, Italy*
*E. Faccioli, Dept. Structural Eng., Politecnico di Milano, Italy*
*R. Paolucci, Dept. Structural Eng., Politecnico di Milano, Italy*
*L. Scandella, Dept. Structural Eng., Politecnico di Milano, Italy*
*W. Stephenson, Institute of Geological & Nuclear Sciences, New Zealand*

Seismic design of buried structures is mainly based on the evaluation of the ground-motion induced strain field, and of the related seismic action effects on the structure. The main drawback of this approach is that it cannot rely upon a direct measure of

the design parameter, strain meters being not generally available in seismic networks. For an indirect measure, simplified formulas relating peak ground strain to peak ground velocity are generally used, based on 1D wave propagation theory in homogeneous media. These formulas, dating back to Newmark's studies, suffer from two main limitations: i) they should not be applied when the structure crosses strong lateral discontinuities in soil properties; ii) even for homogeneous media they strongly depend on the wave type and on the incidence angle, a kind of information that is not generally available to the designer. In this contribution, we consider the weak motion records of a dense temporary network in Parkway Valley, New Zealand. The close spacing of the stations, of the order of few tens of meters, allows us to define with reasonable detail, through a suitable interpolation procedure, the three-component displacement field at ground surface, from which the components of the strain tensor at ground surface are calculated. The observed correlation of peak ground strain vs. peak ground velocity is discussed, highlighting the role of a suitable measure of the apparent wave propagation velocity. Finally, 2D numerical simulations of seismic wave propagation along two representative cross-sections of Parkway valley have been carried out, in order to assess the capability and limitations of the numerical models to accurately reproduce the observed surface ground strains.

### MITIGATION STRATEGY FOR WATER TRANSMISSION PIPELINES UNDER SEISMIC LOADS. THE CASE OF THESSALONIKI – ID 969

*M. Alexoudi, AUTh, Greece*
*A. Hatziathanasiou, AUTh, Greece*
*M. Themistokleous, AUTh, Greece*
*M. Hatzigogos, AUTh, Greece*
*K. Pitilakis, AUTh, Greece*

The main goal of this paper is to estimate the seismic performance of water transmission pipeline from Aliakmona River in Thessaloniki urban area, after the identification of potential seismic hazard. Thessaloniki is a second town in population and importance in Greece and in the last decade, faces serious water supply problems especially in summer months. This transmission water pipeline in full-operation, will solve the supply problem in Thessaloniki till 2040. Moreover, Thessaloniki is located in Servomacedonian massif that is an especially active seismic zone. As result, of the importance of water transmission pipeline and the seismicity of the area, an optimal mitigation solution should be proposed to enhance pipeline reliability especially in the "weak parts" of the linear system. Two seismic scenarios were developed that correspond to maximum historical earthquake and to 100year earthquake return period. Soil characterization was based on Ambrasey's (1996) classification and on EC8. The peak ground acceleration and velocities were estimated using Skarlatoudis et al (2002) relation. For the estimation of liquefaction susceptibility of soil deposits was used Youd and Perkins (1978) methodology. The calculation of lateral spreading was based on the work of Seed & Idriss (1982) and ground settlement on Ishihara (1991) study. The values obtained in a grid points and ArcGIS was used for the spatial distribution of seismic motion in the area and as reliable database for pipeline characteristics. The vulnerability assessment for water transmission pipe was based on O'Rourke & Ayala (1993) and Honneger & Equchi (1992) fragility curve for wave propagation and permanent ground deformations respectively. The differences in system's reliability are provided for pre-earthquake condition without upgrading and after-upgrading comprising both vulnerability and economical cost. Moreover, analysis made, demonstrates the benefits of earthquake preparedness and response strategy at pre-earthquake period taking into account appropriate mitigation policy.

## ES 8 & ES 7: Earthquake Engineering Practice (Recent Projects) and Architectural Aspects, Nonstructural Components and Contents (Joint Session)

Friday 10:45 - 12:15 – Room 23

### SEISMIC STABILITY OF HEAVY STONE FACADES – ID 556

*D. Jurukovski, Institute of Earthquake Engineering (IZIIS), Macedonia*
*Z. Rakicevic, Institute of Earthquake Engineering (IZIIS), Macedonia*

Facades represent important architectural details of buildings and as nonstructural elements could have great impact on structural response during earthquake ground motion. Especially, this is true if heavy stone facades are concerned (150kg/m2 or more), since the added mass will contribute for increasing of overall inertia forces in the main structure. Usually the heavy stones facades are mounted on steel sub-structure, anchored on the structural walls or/and other main structural members. So, the stability of these facades during serviceability period and during seismic event is very important, since their failure or even failure of separate stone blocks can cause serous damages to the main structure and loss of human's life. The problem of seismic stability of heavy stone facades has to be treated in three dimensions, since during an earthquake beside in plane forces presence of out of plane forces could have unfavourable effect too. The way of maintenance of the facades, and treatment for preventing of corrosion of the steel sub-structure will also have influence on the overall stability of these facades. The stone facade manufactured by SONICO, Italy, for the case of building of Aix en Provence, France, was taken as an example on which the seismic stability was investigated. Four different architectural stone facades were installed on reinforced concrete L shape wall, which represent 1:1 scale fragment of the prototype structure. The testing has been performed on biaxial seismic shaking table installed at DYNLaboratory, at IZIIS-Skopje, Republic of Macedonia. Testing programme was prepared in appropriate order and accordingly realized. Large number of experimental data has been collected. In this paper, selected experimental results, recorded for required input level of 0.20g, 0.30g and 0.40g will be presented and discussed. Also, the stability and safety criteria for these type of facades will be discussed.

### SEISMIC DESIGN OF PRE-CAST REINFORCED CONCRETE STRUCTURES USING ADDITIONAL VISCOUS DAMPERS – ID 942

*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*

Precast concrete structures characterised by not moment-resisting frames are characterised by a relatively large flexibility (w.r.t. lateral loads) which may lead to a difficult satisfaction of the performance requirements imposed by the regulations, both in terms of resistance and deformability. This paper illustrates the advantages offered by the insertion of added viscous dampers in such structures with respect to the use of traditional lateral-resisting bracing systems through the case-study of the executive design of a reinforced concrete 2-storey shopping mall building. This paper also presents details of the design process which should be undertaken for the seismic design of structures using additional viscous dampers. The design process may be mainly summarised into two steps: (step 1) preliminary analyses developed using a linear force-velocity relationship for the constitutive law of the viscous dampers and (step 2) analyses carried out with more realistic modelling of the commercially available manufactured viscous dampers. In this connection, two original procedures have been suggested and adopted in the case study: (i) the first one providing for an effective dimensioning of the damping coefficients of the linear added viscous dampers, and (ii) the second one

providing for the passage from a linear (Newtonian) modelling to a non-linear (pseudo-plastic) modelling for the constitutive law of the viscous dampers which leads to similar performances under same inputs.

### MARGINS OF FLOOR SPECTRA – ID 1025

*I. Politopoulos, CEA, France*

The aim of this paper is to have a further insight into the behaviour and analysis of secondary structures, to estimate the margins (positive or negative) inherent in the methods proposed by most earthquake regulations for the design of equipment and components of industrial facilities and to contribute to the determination of less conservative but safe floor spectra.

In a first time we, briefly, discuss margins due to the assumption of no interaction between primary and secondary structures when both of them are assumed to have a linear response.

In a second time, accepting the decoupling assumption, the influence of the non-linear behaviour of the primary structure on the floor spectra is investigated by means of simple models with just 1 or 2 degrees of freedom (DOF).

The general trends of floor spectra for different types of nonlinear behaviour of 1 DOF primary structure are shown and we point out their common futures and their differences. A particular attention is given to the case of an elastic plastic behaviour and a method to determine an equivalent linear oscillator is proposed. The properties (frequency and damping) of this equivalent linear oscillator are quite different from the properties of equivalent linear oscillators commonly considered. Some cases of floor spectra of 2 DOF nonlinear primary structures are also discussed.

At last, the case of nonlinear equipment on a linear main structure is examined. In particular, by means of Monte Carlo simulations we compare the vulnerability of equipment on a seismically isolated building and on a conventional building in the case of a slightly different earthquake excitation than the one considered for the design.

### DYNAMIC ANALYSIS AND DESIGN OF LARGE-DIAMETER LNG TANK FOUNDATIONS TO RESIST SEISMIC EVENTS – ID 1123

*N. Peiris, Arup, UK*
*A. Cushing, Arup, United States*
*Z. Lubkowski, Arup, UK*
*D. Scarr, BP, UK*

On behalf of BP Exploration Company, Ltd, Arup undertook a feasibility study to examine the viability of large-diameter liquefied natural gas (LNG) tanks in areas of low, moderate and high seismicity. For the design of the tank foundations, three generic soil profiles were considered, ranging from dense sand to soft clay. Two primary containment materials were also evaluated: 9% Nickel Steel and Arup's All-Concrete (ACLNG) tank, with volumes up to 300,000 cubic metres.

This paper describes the individual tasks associated with the dynamic soil-structure analysis of the LNG tank-foundation systems, along with the corresponding techniques which were employed in the study. Special attention will be paid to the development of design earthquake spectra, modal analysis of the liquid filled tanks and evaluation of foundation stiffness for the purpose of calculating global inertial axial and lateral loads, consideration of kinematic soil loading, and distribution of shear and moment forces to the foundation elements.

On the basis of these analyses, foundation designs were adopted for each combination of tank type, diameter, seismic zone, and soil profile, which are summarized in the paper. It was found that the construction of a single 300,000 cubic metre LNG tank is technically feasible. Relative foundation material quantities for the various tank options are provided.

### CONFIGURATION AND MORPHOLOGY FOR THE APPLICATION OF NEW SEISMIC PROTECTION SYSTEMS – ID 1185

*M. Mezzi, University of Perugia, Italy*

New design methods, improving the seismic safety of buildings, should consider the system ability to dissipate energy and the effects of the lateral deformation. These considerations involve both the morphological and structural configurations of buildings, nevertheless, so far they have not significantly influenced the fundamental concepts guiding the architectural design. The lack of clear guidelines of seismic architecture becomes more pronounced when adopting new conceptions of structural design and the related innovative techniques. The research is devoted to analyze the relation between architectural morphology, structural configuration and seismic behavior of buildings, when innovative protection systems (base isolation or energy dissipation) are used. The purpose is to outline the criteria leading the architectural conception and the selection of even complex forms, or new architectural morphologies, to achieve a suitable seismic behavior. The basic idea is that some essential characteristics usually considered inappropriate, can be used to enhance damping effects and energy dissipation. The most appropriate structural configurations, taking into account the innovative seismic protection systems, are pointed out. A design methodology based on the study of the main factors, architectural and structural, influencing the seismic response of buildings is developed. The goals consist of organic lists of structural solutions allowing for the optimum articulation of architectural morphologies aiming at seismic protection; suitably outlined architectural configurations including their significant seismic performances; optimum classification of innovative protection systems for the defined morphological classes. Applications carried out on study cases and actual buildings are illustrated.

### RETROFIT OF ANTALYA AIRPORT INTERNATIONAL TERMINAL BUILDING, TURKEY USING SEISMIC ISOLATION – ID 1259

*C. Yilmaz, Metu, Turkey*
*E. Booth, Edmund Booth Consulting Engineer, UK*
*C. Sketchley, Parsons Brinckerhoff, UK*

The international airport terminal building at Antalya, Turkey was completed in 1998 as an in situ reinforced concrete structure, at a time when the site was assigned to Zone 4 of the Turkish code with a seismic coefficient of 0.1. Following a major revision to the Turkish code, which reassigned Antalya to a more seismic zone, design seismic forces for the area increased by 200%. In view of the importance of the building, it was decided that the building should be upgraded to provide a seismic performance at least as good as that required by the new regulations. However, this upgrading had to take place with minimal disruption to the continuing operation of the terminal, which is one of the busiest in Turkey, handling 13 million passengers a year.

After extensive studies, it was decided that the optimal solution was to introduce seismic isolation bearings under the entire building, which covers a footprint area of about 25000 sq meters and rises to a height of 18m above ground. In the absence of a general basement, it was decided that the isolation plane should be 1.5m above ground level. In order to effect this, the columns were temporarily propped, and sections of columns cut out at this level, into which lead rubber bearings were then inserted. In all a total of 350 lead rubber bearings were used, supplemented by some pot and sliding bearings. A rather novel solution was developed to overcome the problem of potential buffeting across expansion joints within the building.

The paper describes the extensive non-linear time history analysis used to justify the design, and outlines the construction methods, which although being used for the first time in Turkey, achieved their goal of timely completion without interruption of operations within the terminal.

## ES 9 & SS 5-I: Lessons from Recent Earthquakes

Tuesday 10:45 - 12:15 – Room 22

### BEHAVIOUR OF MASONRY STRUCTURES DURING THE KASHMIR 2005 EARTHQUAKE – ID 1077

*M. Javed, University of Engineering & Technology, Pakistan*
*A. Naeem Khan, University of Engineering & Technology, Pakistan*
*G. Magenes, University of Pavia, Italy*
*A. Penna, EUCENTRE, Italy*

The October 2005 Kashmir earthquake, causing over 70000 deaths, was one of the worst disasters in the history of Pakistan and of the Indian subcontinent. The vast majority of buildings in the struck area consisted of masonry dwellings, mostly stone. Being in general the low quality of non engineered masonry buildings the main cause of collapse and damage, common sources of vulnerability were recognised, such as: use of rubble stones with irregular courses, use of double stone veneers with no transversal connection, poor quality of mortar, no connection details between orthogonal walls (absence of proper quoins or ring beams or steel tie-rods), absence of bonding elements at floor and roof levels, damage of walls due to out-of-plane thrust from roofs. A critical review of the damage on masonry buildings occurred during the earthquake is presented in the paper, pointing out the main sources of vulnerability, and the measures that could be taken to improve the quality of masonry construction for earthquake resistance.

### PAKISTAN EARTHQUAKE 2005 OCTOBER 8: EARTHQUAKE EXPECTATION AND SEISMIC HAZARD THROUGH TO IMPACT – ID 811

*P. Burton, University of East Anglia, UK*
*S. Cole, University of East Anglia, UK*

The direct impact of the Pakistan 2005 earthquake caused by strong ground shaking and disturbances was immediate destruction of rural civil dwellings and other similarly built structures (Category A and B buildings on MSK and EMS intensity scales) and upwards of 80,000 deaths. This places it among the top 24 worldwide during the last millennium and it exceeds the 30,000-60,000 deaths that accompanied the Quetta 1935 earthquake in Pakistan. Many landslides were induced as a major secondary hazard. The seismicity and apparent seismic hazard in the area, before and after the earthquake, are assessed to examine changing expectations. Methods used range from magnitude and strong ground shaking expectation examined using extreme value distributions through to cumulative strain energy analyses. The extreme value approach establishes new hazard maps for the area for comparison to GSHAP. The cumulative strain energy approach examines both changing expectations of a similar earthquake in this area and also indicates that this earthquake was probably at, or very near, the local maximum credible expectation. The hazard results and related impact implications are compared to and illustrated by observations made in the field during an Earthquake Engineering Field Investigation Team (Institution of Structural Engineers, London) mission to the damage zones during November 2005. This mission observed damage to buildings and also occurrence of landslides and slips of varying sizes. Observations were made on the ground and from low-level flights (Chinook helicopter) and were supported by camera and camcorder photography. The hazard expectations and impact observed arising from the Pakistan 2005 earthquake will be compared and discussed and illustrated using photographic field observations. Contacts: p.burton@uea.ac.uk

### SIMPLIFIED PARAMETERS FOR THE EVALUATION OF SITE EFFECTS IN THE SEISMIC RISK ANALYSES OF MONUMENTS – ID 656

*G. Di Capua, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*E. Curti, DISEG - Università di Genova, Italy*
*A. Lemme, Freelance, Italy*
*S. Peppoloni, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. Podestà, DISEG - Università di Genova, Italy*

In autumn 2002 two moderate energy earthquakes (31 October, 10:32 GMT, Mw = 5.4, and 1 November, 15:08 GMT, Mw = 5.0) struck the provinces of Campobasso and Foggia (southern Italy). The earthquakes attained an intensity VII (Modified Mercalli scale) throughout the epicentral area, except for the village of San Giuliano di Puglia, that suffered an intensity VIII-IX. Damage and vulnerability surveys on monuments (churches) pointed out that the geomorphological site conditions greatly affected the damage level. In particular we found that, for a comparable intrinsic vulnerability of the building, the structural damage level is directly correlated to local amplification phenomena, due to the different morphological and lithological characteristics of each church site. The assessment of damage increase related to local amplification of the ground shaking is made possible by evaluating the damage and seismic vulnerability of each church (e.g., the lack of antiseismic protection, the presence of vulnerability indicators). The damage increase was compared to the morpho-lithological characteristics of each site, schematized with a few simplified parameters. This methodology allows us to evaluate separately a morphological hazard, related to the topographic characteristics of the site and the building location, and a lithological hazard, evaluated on the basis of the Italian seismic code. Our research goal was to set up an expected damage evaluation method, that considers not only the building vulnerability, but also the additional vulnerability related to the church site conditions. The methodology can be effectively used in preventive analyses, targeted to define a priority list of historical buildings and monuments at high seismic risk.

### LESSONS LEARNED FROM THE 1994 AND 2004 AL HOCEIMA (MOROCCO) EARTHQUAKES – ID 935

*F. Vidal, Granada University, Spain*
*M. Navarro, Almería University, Spain*
*T. Mourabit, Abdelmalek Essaadi University, Morocco*
*T. Enomoto, Kanagawa University, Japan*
*E. Ocaña, Granada University, Spain*

The Morocco region presents a moderate seismic activity characterized by earthquakes of small and moderate magnitude (currently lower than 6.5). Recently two destructive earthquakes have occurred in this area: the May 26, 1994 and February 24, 2004 events with magnitude Mw = 6.0 and 6.4, and maximum intensities of grade VIII and VIII-IX (EMS), respectively. The differences and similarities between both earthquake sequences and among their destructive effects have been analysed. The aftershock activity of the two sequences was shallow (<15 km) and distributed on several parallel faults. The main shocks and most of the aftershocks have a similar focal mechanism solution of strike-slip faulting, with the left-lateral nodal plane striking NNE-SSW (compatible with the trends of the faults observed in the area). The observed effects on the ground (cracks, landslides and rock-falls) were in the 2004 earthquake less abundant and smaller in size than in the 1994 event. The most prominent lessons learned in earthquake damage distribution were the influence of the topographical effects in some villages (e.g. Tazarhine and Boukhlifa) in the 2004 earthquake; the high level of damage in masonry rubble stone and mud-fieldstone structures; the surprising low percentage of damage of grade 5 (<10 %) and grade 4 (< 30 %) in adobe masonry structures with double adobe walls; the clear influence of soft-story effect in the collapse of more than 50 reinforced concrete (RC) buildings in Inzourem. The severe and excessive damage in RC buildings was mainly due to bad-design (no seismic code was taken into account), to the use of inadequate materials (e.g. non-corrugated steel and sand for columns), to an insufficient reinforcing layout, to the column and beam sections being very small, to poor column to beam and column to slab connections, and to a very poor construction practice.

### SEISMIC PERFORMANCE OF TYPICAL STEEL AND R.C. BUILDINGS DAMAGED BY THE BAM EARTHQUAKE IN IRAN – ID 236

*N. Hosseinzadeh, IIEES, Iran (Islamic Republic Of)*

The Bam earthquake on 26th December 2003 of magnitude Mw6.5 occurred as the result of right-lateral strike-slip motion of north-south oriented Bam fault which passes from the vicinity of the city of Bam. This earthquake struck this ancient town located about 800km South East of Tehran in Iran. Peak ground acceleration (PGA) of the horizontal components of the earthquake recorded in the centre of the city, were 0.76g perpendicular and 0.60g parallel to the fault direction and 0.98g in the vertical direction. This earthquake with maximum intensity of 9 EMS caused almost total destruction of the town and the surrounding areas with an estimated cost of $10 billion and an approximate loss of 30,000 lives. An important cultural loss was the destruction of Arg-e-Bam, the largest mud-brick complex in the world, located on the historic Silk Road, which is more than 2000 years old. Therefore, practically this earthquake was not only a human catastrophe; it was also a cultural catastrophe for Iran and the world. In this paper, two typical steel braced and reinforced concrete (R.C.) buildings damaged during the Bam earthquake selected for investigation and comparison of the damage level. Linear and nonlinear analyses used for the seismic evaluation and the implications for design practice based on strength and ductility. This study shows that the brittle nature of the fractures detected in weakly welded steel bracing connections essentially invalidated the design approaches and code provisions based on "ductile" structural response. Damage analyses shows that the seismic performance of the R.C. buildings was better than the steel buildings in the region. Basically, the crucial factor in the high levels of death and destruction caused by this earthquake in the new buildings is the lack of implementation of building construction code, not the intensity of the tremor.

## ES 9 & SS 5-II: Lessons from Recent Earthquakes

Thursday 10:45 - 12:15 – Room 3

### GLOBAL ANALYZE OF THE EARTHS SEISMIC ACTIVITY SINCE 80S AND GENERAL LESSONS LEARNT – ID 600

*S. Mara, JRC-IPSC, Romania*
*V. Serban-Nicolae, Babes-Bolyai University Faculty of Environment, Romania*

The paper analyzes a possible increased tendency of earthquake activity (normal is considered that the Earth seismic activity is almost constant in terms of number of earthquakes per decade for a corresponding magnitude), revealed after studying the frequency of the principal major earthquakes magnitudes world over recorded, since 1980's. The results indicated an unusual increased seismic activity, since 90's, which is in contradiction with the generally constant trend of the previous decade. For the evaluation of the earthquakes evolution, in order to find out if revealed any particular trend, were analyzed records over the last 25 years up to now, from USGS, gathered from seismographs from the international survey network. A simple linear correlation was used in order to categorize the trend of the earthquakes activity all over the world. In order to clarify the cause of the unusual increased trend of the earthquakes frequency in certain periods of times after 90's, were took into account diverse assumptions, based with a more detailed analyze of the recent major earthquakes. The detailed analyze of the major earthquakes since 90's, such as Kobe-Japan (1995), Molise,Puglia-Italy (2002), Bam-Iran (2003) and Kashmir-Pakistan (2005), revealed that all these events surprised the local population and local and national level risk managers, because the hit areas were not considered before specifically historically earthquake prone zone, so the building codes were not updated for a real seismic zone (including major cities as Kobe and Islamabad). The seismic analyze is accompanied by general lessons learnt for the risk managers involved in the activities of updating and implementing the building codes, seismic risk zoning and regulation, in order to be avoided in the future any other midjudges of the earthquakes hazard, for minimizing the loss of human lives and material damages.

### EVALUATION OF BUILDING DAMAGES IN THE JUNE 2000 EARTHQUAKES IN SOUTH ICELAND – ID 1194

*N. Indridason, VST Consulting Engineers Ltd., Iceland*
*F. G. Sigtryggsdottir, VST Consulting Engineers Ltd, Iceland*
*A. Gudmundsson, VST Consulting Engineers Ltd, Iceland*

In June 2000, southern part of Iceland was struck by two large earthquakes of magnitude 6.5 and 6.4. Fortunately, there were no casualties. However, the earthquakes caused considerable damage to buildings and their contents.

On behalf of Iceland Catastrophic Insurance (ICI) a team of engineers carried out an extensive damage evaluation of buildings located mainly in two counties in the southern part of Iceland. Consequent insurance compensation comprises 35 M Euros paid out claim due to earthquake related damage.

Comprehensive field survey data along with measurement data offer a great opportunity to study relation between earthquake loading and building damage.

A vast number of pictures were taken describing the damages.

This paper gives an overview of the quantity of damaged buildings, the severeness of the damage and location with regard to the epicentre etc. Furthermore, damage is analysed and grouped with regard to type of buildings and construction parts.

### STATISTICAL ANALYSES ON THE BEHAVIOUR OF BUILDINGS OF SAN GIULIANO DI PUGLIA DURING THE 2002 MOLISE EARTHQUAKE – ID 1750

*A. Masi, DiSGG, University of Basilicata, Italy*
*C. Samela, DiSGG, University of Basilicata, Italy*
*G. Santarsiero, DiSGG, University of Basilicata, Italy*
*M. Vona, DiSGG, University of Basilicata, Italy*

The damage pattern in the area stricken by the 2002 Molise earthquake (Ml=5.4) qualified the event as an intensity VII MCS, with the exception of the village of San Giuliano where, beyond the collapse of the primary school causing 28 deaths, a wide and heavy damage was observed. In November 2002 a team of researchers of the Universities of Basilicata and of Naples surveyed the building stock of San Giuliano collecting data on the structural and damage characteristics. The data were collected by using an upgraded version of the AeDES form, typically used in Italy after a seismic event to evaluate the building usability, and the new MEDEA form. The survey was carried out on all the buildings of San Giuliano, thus providing a complete, homogeneous and reliable set of data to analyse the real performances of buildings and, consequently, estimate their vulnerability. In previous studies (Dolce, Masi and Zuccaro 2003) a preliminary analysis of the data has been performed, showing that the San Giuliano settlement could be subdivided in some zones according to damage and structural types distributions. Whereas high damage levels are present in the urban centre as a whole, strong variations in the different zones have been observed. These variations cannot be explained only by the different vulnerability of buildings but also the role of site amplifications appears significant. For this reason, detailed analyses to assess the influence of the different factors are needed. In the present paper, in order to better understand and quantify the role of the most important parameters, their influence on the building performances is examined by using statistical techniques. After the evaluation of some simple statistics (mean values, coefficient of variations), the data are examined by measuring their association, through a suitable correlation coefficient, and then by performing an analysis of variance.

### PERFORMANCE OF A 3-STOREY RC STRUCTURE ON SOFT SOIL IN THE M6.4 LEFKADA, 2003, GREECE, EARTHQUAKE – ID 1140

*C. Giarlelis, University of Patras, Greece*
*D. Lekka, University of Patras, Greece*
*G. Mylonakis, University of Patras, Greece*
*S. Anagnostopoulos, University of Patras, Greece*
*D. Karabalis, University of Patras, Greece*

An evaluation is presented of the response of a 3-storey reinforced-concrete structure during the 2003 Ms6.4 Lefkada island earthquake. Key aspects of the event include: (1) the unusually strong levels of ground motion (PGA $\simeq$ 0.5g; SAmax $\simeq$ 2.2g) recorded, 12 km from fault in downtown Lefkada; (2) the surprisingly low structural damage in the area; (3) the very soft soil conditions (Vs,max $\simeq$ 150m/s). The building under investigation is an elongated reinforced concrete structure of rectangular plan supported on strip footings, which suffered severe column damage in all floors in the longitudinal direction, yet only minor damage in the transverse direction. Detailed non-linear time-history and spectral analyses highlight the interplay of soil, foundation and superstructure in modifying seismic demand in the two orthogonal directions of the building. It is shown that soil-structure-interaction (SSI) may have adverse effects on inelastic seismic response – contrary to the widespread view of an always-beneficial role of SSI. The response of nearby single-storey structures that suffered little or no damage is compared to that of the building. Structural, geotechnical and seismological aspects of the earthquake are discussed.

### RELATIONSHIP BETWEEN DAMAGE TO NON-STRUCTURAL BUILDING ELEMENTS AND THE SEISMIC INTENSITIES OF RECENT EARTHQUAKES IN JAPAN – ID 726

*H. Kambara, Shimizu Corporation, Japan*
*Y. Hayashi, Kyoto University, Japan*
*K. Tamura, Shimizu Corporation, Japan*

The ability to evaluate damage of nonstructural elements as well as structural elements is essential to estimate functional and economic loss to buildings caused by earthquake shaking. In this study, surveys, in the form of questionnaires were sent out to investigate damage levels of nonstructural elements of buildings in selected areas. The surveys were conducted on selected RC buildings located near earthquake observation points where JMA instruments recorded seismic intensities over 4.0 for any of the past five earthquakes in Japan. The relationship between seismic intensity and damage levels of nonstructural elements were derived from the ratios of buildings with damaged nonstructural elements among all buildings subjected to the same seismic event at same level of intensity in the area. The following characteristics are found by this study for damage of nonstructural elements. a) Damage was mainly detected in exterior and interior walls, window glass, ceilings, doors and elevator equipment, while damage to air conditioning systems and fire protection systems was found less frequently. b) Earthquake shakings at the level of seismic intensity over 5.0 caused significant damage to many kinds of nonstructural elements. c) The percentage of buildings with damaged nonstructural elements increased with the age of the buildings. d) The relationship between seismic intensity and damage of nonstructural elements found in the 2000 Tottori-ken Seibu Earthquake were similar to those found in the 2001 Geiyo Earthquake. For the 2003 Tokachi-oki Earthquake, however, the relationship values for some nonstructural elements were different from those for the above-mentioned two earthquakes. Hence, differences in percentages of damaged buildings in a given area is due to the characteristics of actual earthquake motions even though the seismic intensity observed is consistent.

## STS E1 & SS 6: The Last Mile, Implementation of Risk Mitigation Measures in Europe

Friday 13:30 - 15:00 – Room 23

### SEISMIC CONTROL PROCEDURES FOR BUILDING PROJECTS IN SWITZERLAND – ID 783

*B. Duvernay, Federal Office for the Environment, Switzerland*
*O. Lateltin, Federal Office for the Environment, Switzerland*

In the last decades, tremendous effort and progress has been made in understanding and documenting earthquake hazard and earthquake behavior of structures. These efforts have been translated in modern earthquake hazard maps and state of the art building codes in most earthquake prone regions in Europe and worldwide. Yet, Countless recent disasters have shown that countries having state of the art official building codes still had a high proportion of recent poorly seismically designed buildings leading to high financial and human losses. Furthermore, by the opinion of risk experts, the global seismic risk keeps increasing, thus showing that these "theoretical" instruments are not or not sufficiently translated into actions.

Switzerland is no exception to this general trend. Seismic provisions of building codes are still widely ignored or misused and the general public is still very unaware of the seismic risk. Many construction professionals (mostly architects) discard this problematic from their projects. Taking this into account, the Federal Council has launched a program in 2000 with a series of measures which aim at closing the last mile and achieving a real seismic risk reduction. This program has now been translated into down to earth procedures to ensure that an adequate seismic design is effectively put in place for new buildings and that the opportunity to strengthen existing buildings is systematically evaluated by important retrofit projects. The federal program is unfortunately restricted to federal construction projects and only 2 cantons (states) out of 26 in Switzerland did also implement such procedures for private sector buildings.

In this paper, the nature, efficiency, acceptance and costs of seismic control procedures for building projects in Switzerland are discussed.

### THE APPLICATION OF NON-LINEAR SYSTEM AND CHAOS THEORY IN PREDICTING FREQUENCY OF EARTHQUAKE IN IRAN – ID 185

*S. Imani, university of Tehran, Iran (Islamic Republic Of)*
*H. Soltani-Fard, Uninersity of Tehran, Iran (Islamic Republic Of)*
*M. R. Masnavi, University of Thehran, Iran (Islamic Republic Of)*
*S. Mousavi, E.Azarbaijan&Ardabil Regional Watrer Corporat, Iran (Islamic Republic Of)*

Iran is one of the countries that encounter the most crises in Middle East. Studding this country from historical, political, economical, social etc clear that this country is more often confronting with different natural or non-natural crisis such as revolution, war, terrorist attack, economic prohibition, earthquake, flood etc. Considering average of every decade, people of this country have faced at least with a catastrophic crisis. The main point is that there is some order in their frequency and also complexity in each of them. Life in Iran causes people to face higher levels of risk. Iran's people can be divided in three: 1- The people at risk 2- The people attempt to free of risk 3- The people that have acceptable level of risk. The number of third group is higher than the first and second group. Accordingly, people and government want to reduce the risk of that crises.But uncertainty of lots of problems obstacles reaching this aim. In this paper we want to examine the basic reasons of the crisis emphasizing natural crisis especially earthquakes. Frequency and probability of these events in the next decade of the 21 the century, are estimated by using chaos theory also well pay to the opportunities and treaties that cause increase or decrease of the crisis. Finally this question responded, whether that this country can reach acceptable levels of risk in future or not.

### MANAGING CRISES: EARTHQUAKES IN COMPARATIVE PERSPECTIVE – ID 2019

*M. Malesic, Defence Research Centre, University of Ljubljana, Slovenia*
*V. Kouskouna, University of Athens, Greece*

The record of past events and recent research reveal that Greece and Slovenia are both earthquake-prone countries. The authorities of Greece and Slovenia have developed their own systems of prevention, preparedness, rescue and recovery in case of an earthquake. Scientific cooperation between the two countries sparked the research project "Managing crises: earthquakes in comparative perspective". The research fellows from the National & Kapodistrian University of Athens, Faculty of Geology & Geoenvironment and the University of Ljubljana, Faculty of Social Sciences explore, using a comparative method, earthquakes in historical perspective (Atalanti in 1894 and Ljubljana in 1895) and recent perspective (Posocje 1998 and Parnitha 1999). They explore seismological aspects of events, but also focus on crisis management, using system and functional approaches to the analysis. The research results should consequently provide deeper seismological insights into past and recent earthquakes (seismic parameters, seismic risk assessment, aftershock activity, etc.) and thorough information on the crisis management activity (prevention and mitigation, leadership, perception of crisis, crisis communication, internationalization of crisis and lessons learnt). The latter should be shared by the academic and professional audiences of Greece, Slovenia and other interested countries.

## STS E2: Practice-oriented Nonlinear Approaches for Performance Assessment and Design

Tuesday 10:45 - 12:15 – Room 4

### EVALUATION OF THE MODAL PUSHOVER ANALYSIS PROCEDURE FOR UNSYMMETRIC-PLAN BUILDINGS – ID 1327

*A. Chopra, University of California Berkeley, United States*

Based on structural dynamics theory, the modal pushover analysis (MPA) procedure retains the conceptual simplicity of current pushover analysis procedures with invariant force distribution, now common in structural engineering practice. Recently, the MPA procedure for estimating seismic demands has been extended to unsymmetric-plan buildings. In the MPA procedure, the seismic demand due to individual terms in the modal expansion of the effective earthquake forces is determined by nonlinear static analysis using the inertia force distribution for each mode, which for unsymmetric buildings includes two lateral forces and torque at each floor level. These "modal" demands due to the first few terms of the modal expansion are then combined by the CQC rule to obtain an estimate of the total seismic demand for inelastic systems. When applied to elastic systems, the MPA procedure is equivalent to standard response spectrum analysis (RSA). The proposed paper evaluates the accuracy of the MPA procedure against the "exact" nonlinear response history analysis (RHA) for a range of unsymmetric-plan multistory systems. The selected systems represents different degrees of coupling between lateral and torsional motions, as characterized by different values of the ratio of uncoupled lateral and torsional periods: a torsionally-stiff system, a torsionally-flexible system, and a torsionally-similarly-stiff system. The MPA estimates of seismic demand for torsionally-stiff and torsionally-flexible unsymmetric systems are shown to be similarly accurate as they are for the symmetric building; however, the results deteriorate for a torsionally-similarly-stiff unsymmetric-plan system and the ground motion considered because (a) elastic modes are strongly coupled, and (b) roof displacement is underestimated by the CQC modal combination rule [which would also limit accuracy of response spectrum analysis (RSA) for linearly elastic systems]. This pilot study has pointed to the need for evaluating the MPA procedure for unsymmetric-plan buildings considering an ensemble of ground motions.

### THE N2 METHOD FOR ASYMMETRIC BUILDINGS – ID 539

*P. Fajfar, Univ. of Ljubljana, Slovenia*
*D. Marušic, Univ. of Ljubljana, Slovenia*
*I. Peruš, Univ. of Ljubljana, Slovenia*

The N2 method represents a relatively simple and efficient tool for simplified nonlinear analysis of structures. The basic version of this method has been implemented in Eurocode 8 (Annex B of Part 1). The method is based on pushover analysis. Seismic demand is determined from inelastic spectra and depends on the period of the idealized equivalent SDOF system. The transformation from the MDOF to an equivalent SDOF system is based on the assumption of a time-invariant displacement shape. This assumption represents the major limitation of the applicability of the method. It works well in the case of planar structural models with small influence of higher modes. In the case of asymmetric building structures, represented by a 3D structural model, several modes may substantially contribute to the response and the torsional effects may not be properly taken into account by a straightforward extension of the N2 method to 3D models. The results of recent parametric studies suggest that in the majority of cases an upper limit for torsional effects can be estimated by a linear dynamic (spectral) analysis. Based on this observation, it is proposed that the results obtained by pushover analysis of a 3D structural model be combined with the results of a linear dynamic (spectral) analysis. The former results control the target displacements and the distribution of deformations along the height of the building, whereas the latter results define the torsional amplifications. In the paper, the extended N2 method is summarized and applied to several test examples. The results are compared with results of nonlinear dynamic time-history analyses.

### FACILITATING THE SELECTION OF EFFECTIVE STRUCTURAL SYSTEMS IN PERFORMANCE-BASED DESIGN – ID 1272

*F. Zareian, Stanford University, United States*
*H. Krawinkler, Stanford University, United States*

This paper focuses on providing a simple and practical approach for Performance-Based Design (PBD). The process for probabilistic Performance-Based Assessment (PBA), as developed recently in various organizations (e.g., Pacific Earthquake Engineering Research Center), implies that, given a building and its location, one can rigorously calculate the corresponding losses (e.g. expected dollar loss at certain hazard level or mean annual frequency of collapse). Although this process is mathematically powerful and accounts for losses of all structural and non-structural components, its implementation in practice is rigorous and in many cases impractical. Also, it is neither practical nor efficient to use this approach for Performance-Based Design (PBD). Design is different from assessment by virtue of the fact that the building first needs to be created. In the simplified PBD approach proposed in this paper, performance is defined by several performance objectives that place limits on direct (monetary) loss, downtime loss, and life loss (or tolerable probability of collapse). The proposed design process incorporates different performance objectives up front, before the structural system is created, and assists engineers in making informed decisions on the choice of an effective structural system and its stiffness (period), base shear strength, and other important global structural parameters. The tools needed to implement this design process are (1) hazard curves for a specific ground motion intensity measure, (2) mean loss curves for structural and nonstructural subsystems, (3) structural response curves that relate, for different structural systems, a ground motion intensity measure to the engineering demand parameter (e.g., interstory drift or floor acceleration) on which the subsystem loss depends, and (4)

collapse fragility curves. The proposed process is illustrated in an example to demonstrate its practicality.

## STS E3: Irregular Structures.

Tuesday 13:30 - 15:00 – Room 23

### EAEE TASK GROUP (TG) 8: SEISMIC BEHAVIOUR OF IRREGULAR AND COMPLEX STRUCTURES: PROGRESS SINCE 2002 – ID 1443

*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*

The interest in seismic behaviour of irregular structures has intensified in recent years. In this paper, published research on the seismic response of irregular, both plan-wise and vertically, structures since 12th ECEE in 2002 is briefly reviewed. It is shown that most papers deal with the following topics: - Asymmetric single and multi-storey buildings - Vertically irregular and set-back structures - Seismically isolated and controlled structures Prediction of nonlinear dynamic response by means of pushover analysis and code-related issues have been also investigated, while few paper have been reporting experimental results.

### COMPARISON OF 2D AND 3D PUSHOVER ANALYSIS WITH TIME HISTORY ANALYSIS IN ASYMMETRIC BUILDINGS – ID 447

*F. Forootan, Azad University, Iran (Islamic Republic Of)*
*A. S. Moghadam, IIEES, Iran (Islamic Republic Of)*

In this paper the drift response of multistory asymmetric buildings are compared using 2D, 3D pushover analyses and nonlinear time history analysis. The structure models are mass or stiffness eccentric multistory three dimensional steel moment resisting frames with bracings at the external frames. The structures are subjected to seven earthquake ground motions and the edge displacement ratio of the frames to the displacement of the center of mass is defined as a coefficient to consider the effect of eccentricity and asymmetry. The target displacement of the structure and each individual frame is calculated by the relevant formulas and are multiplied by the coefficient. 2D & 3D pushover analyses are conducted and the drift responses of the building in different frames are compared with time history analyses. The result shows that the procedure of determining target displacement in pushover methods should be modified to provide conservative results suitable for design purpose.

### IMPORTANCE OF ACCIDENTAL ECCENTRICITY FOR THE INELASTIC EARTHQUAKE RESPONSE OF BUILDINGS – ID 1192

*K. Stathopoulos, DOMI, Greece*
*S. Anagnostopoulos, University of Patras, Greece*

The purpose of accidental eccentricity that modern codes specify for earthquake resistant building design is to account for torsion due to factors difficult to predict, quantify and explicitly consider. Such factors are unknown distributions of live loads, uncertainties in member stiffness, non-structural elements, rotational components of ground motion, etc. The accidental eccentricity provisions vary among different codes and are all based on elastic response considerations. The present paper presents an extension of earlier work where this problem was investigated using both simplified and detailed inelastic models of the shear beam and the plastic hinge type, respectively. The detailed models were three and five story frame buildings with physical eccentricities of 0.0 (symmetric), 0.10 and 0.20, and were all designed for different accidental eccentricities, including those specified by EC8 and by IBC 2000. Originally these models were subjected to a group of ten semi-artificial motions, compatible with the design spectrum. The extension consists in generating and analyzing variants of the 3 and 5-story buildings, designed both with zero and 5% accidental eccentricity, where their physical eccentricities of 0.0 (symmetric), 0.1 and 0.2 were modified by introducing an extra 5% " accidental" eccentricity in both directions. The results are expressed in terms of beam rotational ductility factors and damage indices. They indicate that the accidental eccentricity is not very effective in reducing ductility demands or the damage index. In fact, in several occasions the designs with zero accidental eccentricity exhibited ductility demands, in some locations at least, less than those with accidental eccentricity. These findings suggest that the accidental eccentricity provisions in the codes, especially the more complicated ones as in the IBC2000, should be re-examined, in view of the additional computational requirements they impose on designers.

### POST-TEST ANALYSIS AND INTERPRETATION OF THE RESULTS OF PSD TESTING ON A FULL-SIZE THREE-STOREY RC PLAN-WISE IRREGULAR BUILDING – ID 76

*P. Negro, JRC, Italy*
*E. Mola, Politecnico di Milano, Italy*

In the framework of the research activity of the ELSA Laboratory of the Joint Research Centre, pseudo-dynamic testing of a real-size plan-wise irregular 3-storey frame structure, both in the 'as-buit' and in two retrofitted configurations, was carried out as the core of the research project SPEAR (Seismic PErformance Assessment and Rehabilitation of existing buildings). The experimental activity carried out on the SPEAR structure allowed a one-of-a-kind wealth of data to be collected, in a field where, until now, experimental validation of a long-lasting and lively debate in the earthquake engineering community has been insufficient: that of the seismic behaviour of plan-wise irregular structures. Once in the post-test phase, it became clear that a good understanding of the complex features of the response of the specimen was difficult to be obtained, due to the effects of double eccentricities, adding up to poor structural detailing and lack of ductility. For this reason, it was decided to apply to the most significant collected data series the Karhunen-Loéve (K-L) (or principal component analysis) method. The method, applied to the analysis of the data collected in the test in the original and in the two different retrofitted configurations, allowed conclusions to be drawn on the relative effectiveness of the retrofitting strategies in affecting the seismic response and eventually in reducing the averse torsional effects in the response. Moreover, the energy dissipation patterns in the different configurations were analysed in a modal perspective. The final aim of the paper is to put the obtained results in a performance-oriented perspective, in the framework of the currently open discussion on the parameters of election to be taken into account in the design or assessment phase in order for the engineer to correctly predict or originate the desired behaviour in the presence of plan irregularity inducing twisting effects.

### NONLINEAR TIME HISTORY ANALYSIS WITH TEST VERIFICATION OF AN IRREGULAR BUILDING – ID 253

*Y. Zhou, Research Institute of SE and Disaster Reduction, China*
*X. Lu, State Key Laboratory for Disaster Reduction in CE, China*

Shapes of high-rise city buildings are becoming increasingly unique and complicated owing to the commercial or aesthetic considerations. This brings challenges to structural engineers in analyzing and predicting their dynamic response, which is crucial to the safety of the buildings. A detailed study is required to verify the seismic safety and rationality of the design. This paper presented the results of shaking table model test and nonlinear time history analysis both performed for a high-rise building with two large openings (20m by 20m) in elevation. In the dynamic test, the model suffered two earthquake inputs and an artificial earthquake simulation under frequent, basic and rare occurrence of seismic levels, respectively. Acceleration response was measured and cracks were observed with the increase of input intensity of earthquake simulations. Model displacement was achieved

by integrating the acceleration twice. In the analysis, nonlinear structural responses were reflected by calculating member skeleton curve in specified software and then inputting them in the finite element program. Analytical results, including model frequencies, time-history and envelop of displacement, were compared to the experimental responses, and accordingly the seismic performance of the building structure was evaluated. It was concluded that both the experimental and analytical models could obtain the accurate dynamic property of the irregular high-rise building. The structural design has been improved based on the structural vulnerable position evaluation of the dynamic model test and time-history analysis.

### OPTIMAL INSERTION OF VISCOUS DAMPERS INTO TORSIONALLY COUPLED STRUCTURES – ID 949

*G. Gasparini, DISTART - Department of Civil Engineering, Italy*
*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*

Structures characterized by non coincident center of mass and center of stiffness, also referred to as eccentric structures, develop a coupled lateral-torsional response when subjected to seismic excitation. This coupled behaviour may increase significantly the local peak dynamic response of such a structure, as compared to that of an equivalent system with coincident center of mass and center of stiffness (equivalent non-eccentric system). In recent years, a number of innovative earthquake-engineering techniques, such as active, passive or hybrid active/passive earthquake protection systems, have been developed and implemented in actual building constructions. Among passive protection systems, added viscous dampers have proven so far to be easily applicable and highly effective. In this paper, the effects of inserting a system of added dampers into eccentric structures are investigated with reference to linear elastic one storey stiffness eccentric structures subjected to seismic excitation. The goal of the research study here described is the identification of the "optimal" system of added viscous dampers capable of minimising the seismic induced torsional effects. In detail, the paper introduces an optimisation procedure based upon genetic algorithms and the use of selected response indexes based upon the mean square response to stochastic inputs of the eccentric systems. The stochastic response is here evaluated with reference to a white noise input. Viscous dampers are modelled using a linear constitutive law. The effectiveness of the proposed optimisation procedure is here measured with reference to the response of eccentric systems as subjected to historically recorded ground motions.

## STS E4: Displacement Based Design: Initial Versus Secant Stiffness

Tuesday 15:30 - 17:00 – Room 1

### INITIAL STIFFNESS OR SECANT STIFFNESS FOR SEISMIC DESIGN - WHICH IS MORE APPROPRIATE? – ID 469

*N. Priestley, Rose School, Italy*

The paper examines and compares the concepts of seismic design using initial stiffness and secant stiffness to characterize ductile response. Initial stiffness is the current basis of almost all seismic design codes, and thus has the merit of familiarity, which should not be underestimated. Clearly, if improvements to seismic design can be logically implemented within the framework of an initial stiffness/behaviour factor approach, this is to be desired. There are, however, severe limitations to the initial stiffness approach that are more readily resolved by use of a displacement-based procedure utilizing secant stiffness. These limitations include the determination of the appropriate behaviour factor for mixed structural systems (e.g. walls+frames), the assumption that displacement demand can be estimated based on the elastic stiffness (e.g. the equal displacement approximation), and the assumption that the initial stiffness can be estimated at the start of the design process, before strength is known. These points are elaborated in the paper.

### REFLECTIONS ON THE USE OF ELASTIC OR SECANT STIFFNESS FOR SEISMIC EVALUATION AND DESIGN OF STRUCTURE – ID 1476

*E. Miranda, Stanford University, United States*

Current seismic design criteria make use of either initial stiffness or secant stiffness for preliminary design of new structures and for evaluation of existing structures. The use of these approaches is closely related to the choice of approximate methods to estimate peak deformation demands. Displacement based approaches that use initial stiffness are typically used in combination with methods based on displacement modification factors while displacement based approaches based on secant stiffness are commonly used in combination with equivalent linear approaches. This paper examines both approaches and provides some observations on them. It is shown that, contrary to the prevalent notion that for medium and long period structures displacement demands are independent of lateral strength, weaker structures have a larger probability of exceeding maximum tolerable displacements and of exhibiting dynamic instability. Similarly, and contrary to the commonly used assumption that peak deformation in nonlinear structures depends on the energy dissipation capacity (area inside the hysteresis loop), it is shown that peak deformation demands are not strongly influenced by this structural characteristic. Similarly, several examples are used to illustrate that period-independent equations commonly used in equivalent linear methods to estimate equivalent damping ratios and period shifts may lead to considerable errors in the case of short period structures. Furthermore, equivalent linear approaches may lead to multiple solutions with no clear guidance as of which one is correct. Improvements to both approaches are proposed. It is shown that, if adequately implemented both approaches may lead to adequate results, however, both approaches involve considerable uncertainties which need to be properly accounted for. Special emphasis is placed on the level of approximation that these methods provide and how to take into account uncertainties in a rational framework.

## STS E5: Eurocode 8 : How to Apply ?

Thursday 13:30 - 15:00 – Room 4

### THE SELF-SUFFICIENCY OF EUROCODE 8 AND THE APPLICABILITY OF COMPLEMENTARY DOCUMENTS - THE SITUATION – ID 310

*M. Fardis, University of Patras, Greece*

EN1998-1:2004 and EN1998-5:2004 were published by CEN as European Standards in Nov. and Dec. 2004. EN1998-2:2005, EN1998-3:2005 and EN1998-6:2005 were published as European Standards between June and Nov. 2005. Two years from these dates CEN Member States should have published the National Annexes to these ENs. According to the European Commission, EU States should adopt the EN-Eurocodes as a suitable means for structural design, refer to them in their national provisions on structural construction products, base on them the technical specifications in contracts for works and related engineering services in the public sector and in the water, energy, transport and telecommunications sectors, and promote them in private contracts over national regulations. National choice through the National Annex will be limited to the "Nationally Determined Parameters", which are symbols (e.g. safety factors, return period of design seismic action), technical classes (e.g. ductility classes) and procedures/methods fully described in the normative text. National Annexes may also provide complementary information, non-contradictory to the EN-Eurocode rules, to assist users to apply the EN-Eurocode.

Eurocode 8 itself invites for such information items not fully covered in its scope complementary to Eurocode 8 for items not fully covered in its scope, f.i., for the combination of non-independent modes or of the maximum vectorial action effects of different seismic action components. Other such items are flat slabs in buildings, prestressing in dissipative zones of concrete members, member models in nonlinear analysis, or mechanical models of masonry infill panels for their explicit modelling in analysis. National Annexes cannot modify or replace any EN-Eurocode rule. Although discouraged, such deviations from the EN-Eurocode are allowed in national regulations other than the National Annex. However, a design that uses deviating national regulations cannot be called "design according to EN-Eurocodes".

### APPLICATION OF EUROCODE 8 IN SWITZERLAND – ID 1399

*T. Wenk, Switzerland*

In 2003 a new generation of structural standards based on the Eurocodes were published in Switzerland. Instead of simply taking over Eurocode 8 as independent seismic documents, a different approach was selected. The seismic regulations of Eurocode 8 were integrated in the action code and in the different material related codes. At the same time, Eurocode 8 regulations were condensed to the principles and to a minimum of application rules suitable for a country with low to medium seismicity. The Swiss integration approach allowed to eliminate certain contradictions between different Eurocodes and to produce a more userfriendly code suitable for practical use.

## STS E6-I: Seismic Assessment and Retrofit of Bridges

Wednesday 10:45 - 12:15 – Room 23

### AN ADAPTIVE CAPACITY SPECTRUM METHOD FOR ASSESSMENT OF BRIDGES SUBJECTED TO EARTHQUAKE ACTION – ID 511

*C. Casarotti, Structural Mechanics Dept.,University Pavia, Italy*
*G. M. Calvi, Structural Mechanics Dept.,University Pavia, Italy*
*R. Pinho, ROSE School, Italy*

Estimating seismic demands on structures, to predict their performance level with confidence, requires explicit consideration of the structural inelastic behaviour: to this end, the use of nonlinear static procedures is inevitably going to be favoured over complex nonlinear time history methods. The currently proposed assessment procedures have been tested predominantly against building frames. A newly derived assessment procedure is proposed within the scope of bridge applications, based on an innovative displacement-based adaptive pushover technique. The procedure, which can be incorporated into a performance-based engineering philosophy, is applicable to MDOF continuous span bridges with flexible or rigid superstructures, and for varying degrees of abutment restraint. As a first application to determine the viability of the proposed procedure, a parametric study is conducted on a ensamble of bridges subjected to earthquake motion. It is shown that, compared to the seismic demand estimated by means of the more accurate nonlinear dynamic analysis tool, the novel static assessment method can lead to the attainment of satisfactory predictions, both in terms of displacement as well as moment demand on members.

### A METHODOLOGY FOR DERIVATION OF SEISMIC FRAGILITY CURVES FOR BRIDGES WITH THE AID OF ADVANCED ANALYSIS TOOLS – ID 275

*A. Kappos, Aristotle University, Greece*
*I. Moschonas, Aristotle University, Greece*
*T. Paraskeva, Aristotle University, Greece*
*A. Sextos, Aristotle University, Greece*

Within the framework of a major research programme ('ASProGe: Seismic Protection of Bridges') coordinated by the Laboratory of Concrete and Masonry Structures of the Aristotle University of Thessaloniki, the need arose for deriving seismic fragility curves for all types of bridges commonly found in the motorway system of Greece; these bridges can be considered as representative of current seismic design practice in Southern Europe. These fragility curves will be use, among other applications, as part of the seismic risk management system of the bridges along the 680km long Egnatia Motorway (some of which are instrumented within the framework of ASProGe). Several methods are currently being tested for producing fragility curves for a total of ten different types of concrete bridges, identified as the most common ones in Egnatia. The analysis of these bridges is carried out using advanced inelastic tools developed by the authors, which include, among others § modal pushover analysis based on appropriately selected monitoring points for drawing the pushover curves, and the popular demand and capacity spectra approach § time history analysis accounting for the influence of spatial variability of earthquake ground motion on both straight and curved bridges, as well as of soil-foundation-superstructure interaction The fragility curves are drawn assuming a lognormal distribution, and constructing the basic relationship between intensity of ground motion and bridge damage state using either pushover analysis or dynamic time history analysis. The former relationship then yields the damage state threshold values for the fragility curves (five states are considered), which are defined differently in bridges with yielding piers (of the column type), and bridges with elastomeric bearings and non-yielding piers of the wall type. Two examples of fragility curves will be presented, one for each of the aforementioned types.

### FRAGILITIES OF PEER TESTBED BRIDGES – ID 1219

*K. Mackie, University of California Berkeley, United States*
*B. Stojadinovic, University of California Berkeley, United States*

Multiple-span reinforced concrete highway overpass bridges constitute a large number of the total inventory of bridges in California, particularly bridges of new design. Performance of these bridges is therefore integral in the evaluation of transportation network performance under high-intensity earthquake scenarios. Additionally, probabilistic quantification of bridge response and vulnerability provides insight into the evaluation of current designs at different levels of seismic hazard for design and planning purposes. Fragility curves depict the probability of exceeding performance goals at the demand, damage, and loss levels, conditioned on the intensity of ground motion experienced by the bridge. The Pacific Earthquake Engineering Research (PEER) Center's performance-based earthquake engineering framework was used to generate the bridge fragilities.

In this paper, two typical single column-per-bent, five-span, post-tensioned box girder reinforced concrete highway bridges of new design are analyzed. The first bridge has a straight deck and 6.7m columns of equal height above grade. The second bridge has 15.2m column heights. Each bridge type has a variety of column designs for different seismic demands. A complex model of the structures is created using the OpenSees platform that accounts for nonlinear behavior of the columns, deck, abutments, and expansion joints at the abutments. Seismic demand models are then developed using nonlinear time history analysis, including under near-field excitation. Damage in the columns is then determined from a database of experimental tests and approximate repair cost ratios are estimated from the assumed discrete damage states. Fragilities comparing the two basic bridge types are presented for demand (drift ratio), damage to the bridge columns, and repair cost ratio.

### PROBABILISTIC SEISMIC SAFETY ASSESSMENT OF BRIDGES - APPLICATION TO A REAL CASE – ID 1144

*P. Delgado, Instituto Politécnico de Viana do Castelo, Portugal*
*R. Monteiro, Faculdade de Engenharia da Universidade do Porto, Portugal*
*M. Marques, Faculdade de Engenharia da Universidade do Porto,*

*Portugal*
*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*

The main scope of the paper is to present a probabilistic methodology for the structural safety assessment and its application to a real case in order to evaluate its seismic safety. The paper has been settled within the LESSLOSS project – A European Integrated Project on Risk Mitigation for Earthquakes and Landslides – which consists in the development of methods for seismic fragility analysis of structures. These methods will account for uncertainty in seismic motion, mechanical parameters, capacity models, and for multiple correlated modes of failure. The main objective is to apply the probabilistic methods to real structures to assess their validity and practicability. In this work, the real structure under analysis is a bridge – the Lordo viaduct – recently designed in a seismic area of Southern Italy. The structural modelling of the bridge is carried out using a non-linear plane model and a step-by-step dynamic analysis. The study involves a preliminary elastic analysis, where mass, geometry and modal characteristics are defined, followed by a detailed safety/vulnerability assessment analysis. For this last one, several intensity levels of earthquake ground motion are considered to achieve the corresponding failure probabilities, the points of the structural fragility curve. In addition, it is also presented the vulnerability function, the mean ductility demand as a function of the intensity level, which enables to evaluate the global failure probability.

### MODELING OF EMBANKMENT FLEXIBILITY AND SOIL-STRUCTURE INTERACTION IN INTEGRAL BRIDGES – ID 125

*A. Kotsoglou, Demokritus University of Thrace, Greece*
*S. Pantazopoulou, Demokritus University of Thrace, Greece*

Observations from response records of instrumented integral bridges as well as available seismic records of embankment soil displacements support the conclusion that flexible embankments participate in the dynamic response of integral bridges by developing significant transverse displacements in the abutments [Painter Street Overcrossing and Meloland Road Overcrossing, California Strong Motion Instrumentation Program]. The extent of movement depends on many design parameters of the bridge, including the type of abutment foundation, ground motion characteristics, and overall bridge geometry. Previous analytical studies have demonstrated, however, that because the soil is highly nonlinear under reversed cyclic deformation, the embankments become more compliant with increasing earthquake intensity, carrying along the abutments during this motion. Therefore, an alternative load path develops in integral concrete bridges, where intermediate piers or bents become follower elements; in such cases, overall bridge response to transverse excitation is driven primarily by the flexible embankments. Embankment flexibility and dynamic response of the overall system considering soil structure interaction are the central issues explored in the present paper. Objective is to investigate quantitatively and qualitatively the contribution of the embankments flexibility to the system dynamic response under strong intensity ground motions. Using a detailed three-dimensional nonlinear finite element model, based on inelastic constitutive relationships of the materials involved, an explicit representation of the system is implemented. Dynamic response is evaluated to a series of earthquake records of variable intensity. In addition, the analytical solution of the problem is obtained and parametric sensitivity of the results to the main design variables is explored through systematic comparisons. A new simplified model is developed to describe the response of the overall system accounting for the embankment contribution.

## STS E6-II: Seismic Assessment and Retrofit of Bridges

Wednesday 13:30 - 15:00 – Room 23

### SEISMIC RETROFIT OF BRIDGE - A JAPANESE PRACTICE – ID 825

*K. Kawashima, Tokyo Institute of Technology, Japan*

An important aspect of seismic retrofit is that difficult restrictions and requirements in retrofit design sometimes validate to use new materials and construction methods. Consequently seismic retrofit is a good opportunity for engineers and researchers for challenging to use new and high performance materials and to develop new construction methods. Seismic retrofit follows the standard seismic design and construction procedures for a new bridge. The only difference with design of a new bridge is that actual strength and capacity instead of nominal values should be used in retrofit design. Options of seismic retrofit depend on materials and construction methods available.

Seismic retrofit of bridges has been extensively conducted to existing bridges in Japan, in particular since the 1995 Kobe earthquake. For example, over 30,000 bridge columns were retrofitted. This paper introduces the current practice on the seismic retrofit of bridge columns in Japan. The seismic retrofits with various measures are introduced with typical application. The standard measure for single columns is steel jacketing and reinforced concrete jacket. Reinforced plastics such as carbon fiber sheet and aramid sheets are extensively used. Special technical development for implementation of the retrofit to columns with extreme boundary and surrounding conditions has been conducted. Loading verification tests for major retrofit are also included.

### ASSESSMENT AND UPGRADING OF RESISTANCE AND DEFORMATION CAPACITY OF CONCRETE PIERS – ID 315

*D. Biskinis, University of Patras, Greece*
*M. Fardis, University of Patras, Greece*

Seismic assessment of existing bridge piers is nowadays done by comparing deformation demands induced in them by the seismic action to their cyclic deformation capacity, as controlled by flexure or shear. To this end, the pier cyclic deformation capacity should be determined, as affected by insufficient confinement or short lap splices in the plastic hinge region, or by degradation with post-elastic cyclic deformations of the pier shear resistance (controlled by diagonal tension in slender piers, or by diagonal compression in squat piers). Moreover, for the pier seismic deformation demands to be reliably determined, realistic estimates of their effective stiffness up to yielding should be available. In this paper, a large number of monotonic or cyclic test results on circular or hollow rectangular concrete piers are used to develop or calibrate: - rules for calculation of the yield moment of the pier, as controlled by short lap splicing; - expressions for the pier chord rotation at yielding and the resulting secant stiffness to yielding; - semi-empirical expressions for the cyclic shear resistance of the pier in diagonal tension or compression, before or after flexural yielding; and - expressions for the pier ultimate chord rotation in cyclic loading, as affected by short lap splices. FRP wrapping of the plastic hinge region is becoming the method of choice for enhancement of the cyclic deformation capacity of existing concrete members, especially of those with insufficient confinement or short lap splices. Cyclic test results on circular or hollow rectangular concrete piers retrofitted through FRP wrapping are used to develop or calibrate rules or expressions for the determination of such wrapping on: - the flexural resistance of piers with short lap splices; - the resistance in cyclic diagonal tension after flexural yielding; and - the cyclic ultimate chord rotation of piers with short lap splices.

### EXPERIMENTAL CYCLIC TESTS AND RETROFIT OF RC HOLLOW PIERS – ID 1205

*P. Delgado, Instituto Politecnico de Viana do Castelo, Portugal*
*P. Rocha, Instituto Politecnico de Viana do Castelo, Portugal*
*V. Rodrigues, Faculdade de Engenharia da Universidade do Porto, Portugal*
*M. Santos, STAP, Portugal*
*A. Arêde, Faculdade de Engenharia da Universidade do Porto, Portugal*
*N. Vila Pouca, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*
*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*

The main purpose of this paper is to present an experimental campaign of reinforced concrete piers with different cross section under cyclic loading, comparing the obtained results with the ones obtained for the same piers after seismic retrofitting, and evaluating benefits concerning their structural behavior. The setup of the RC piers experimental tests was designed to carry out cyclic top displacements with axial load. Such biaxial loading was performed using two orthogonal actuators with a slide device to allow the pier top displacements, once the vertical actuator was fixed connected to a steel portal frame. Representative of the typical bridge construction, these RC piers structural behavior and structural safety improvement of the several retrofit techniques adopted, are presented, as well as the illustration of the outside and inside damage pattern. Within the scope of this work is, therefore, to develop and calibrate procedures that enable the evaluation of the different retrofit solutions efficiency, their possibilities and fields of application.

### SISMOA : A SIMPLIFIED METHOD TO ASSESS THE SEISMIC VULNERABILITY OF EXISTING BRIDGES – ID 150

*P. Marchand, SETRA, France*
*D. Davi, SETRA, France*
*P. Schmitt, SNCF, France*
*C. Thibault, CETE Méditerranée, France*
*A. M. Duval, CETE Méditerranée, France*
*D. Criado, CETE Meditérranée, France*

Initiated in 1997 under the supervision of the Directorate of Roads of the French Ministry of Public Works and Transportations, the SISMOA method was created in order to estimate the vulnerability of existing bridges under seismic actions. Based on geometrical and typological criteria, this qualitative method resulting from the vulnerability assessment of the different parts of bridge structures such as the deck, abutments, piers, foundations. . . , was tested with success on several seismic critical areas of the French territory, chosen to be representative of a certain type of construction as well as social and economical aspects. The purpose at that time was to get a tool able to determinate which bridges should be retrofitted in priority in order to meet seismic requirements.

In 2002, the Directorate of Roads decided to extrapolate the method, from isolated bridges approach to road sections approach. This significant development supposed to perform the same kind of analysis on other structures like retaining walls and tunnels and also to deal with other types of seismic induced hazards than code accelerations, such as liquefaction hazard, site effects, landslides, rock fallings, including deterministic and probabilistic scenarios...

Consequently, the SISM0A method was extended to tackle the vulnerability of a given bridge to environmental hazards such as liquefaction, landslides and rock fallings.

This presentation will mainly focus on the vulnerability analysis of bridges. Vulnerability of retaining walls and global risk assessment methodology for road sections using a GIS tool will be the respective matters of two additional proposed papers referring to SISMUR and SISROUTE methods.

### BRIDGE ASSESSMENT IN REGIONS OF MODERATE SEISMICITY - A CASE STUDY – ID 1256

*M. Bimschas, Institute of Structural Engineering, ETH Zurich, Switzerland*
*A. Dazio, Institute of Structural Engineering, ETH Zurich, Switzerland*

Switzerland is - compared to other regions throughout the world - a country of moderate seismicity. Research during the last decades has shown that the seismic hazard in Switzerland has been underestimated significantly in the past. This has lead to pronouncedly more restrictive provisions concerning the design of new bridges over the last generations of codes. Since the large majority of bridges in Switzerland has been built before those latest provisions were established, their seismic safety is unknown and might be insufficient from today's perspective. Hence, it has been decided that the existing stock of Swiss bridges shall be assessed in order to determine their vulnerability. Technically, this could be done using the force-based design provisions of the current codes. However, this would not be appropriate since these do not explicitly take the deformation capacity of an individual bridge into account and might thus be unrealistically conservative. Therefore a research project is currently underway at ETH Zurich which aims at developing more appropriate assessment procedures. These should, at one hand, provide sufficient accuracy to describe the bridges' behavior realistically and, at the other hand, be efficiently applicable to a large stock of bridges at reasonable effort. This paper presents the analysis results of a multi-span bridge with continuous superstructure which shows typical characteristics and weaknesses of existing Swiss bridges built in the late 1960s. Different methods including nonlinear static and dynamic analyses are being applied to estimate the seismic demand of the bridge. The results are compared among each other as well as with the bridge's capacity. Furthermore, the study gives insight into the appropriateness of the various approximate analysis techniques with respect to the usually low ductility capacities of existing bridges. It also highlights typical weak spots and problem cases that exist even in regions of moderate seismicity.

## STS E7: European Research on the Performance of Experimental Facilities

Monday 13:30 - 15:00 – Room 22

### EUROPEAN RESEARCH ON THE PERFORMANCE OF EXPERIMENTAL FACILITIES – ID 367

*R. Severn, The University of Bristol, UK*

In 1992 the shaking table laboratories at LEE Athens and EERC Bristol received an EC contract to study the true performance characteristics of their facilities. They were quickly joined by LNEC Lisbon and ISMES Bergamo. The main conclusions from this study was that shaking tables could not be controlled if the physical properties of the testpiece changed during the test, and that the tests could not be carried out in real-time. It was clear that our laboratories had not been aware of developments that had taken place in control engineering, particularly the work in Bristol University on medical robotics using the adaptive Minimal Control Synthesis (MCS) algorithm, the word 'adaptive' meaning that it altered the control parameters as the physical characteristics of the testpiece changed. Also, making use of faster computers, it became possible to achieve operation in real-time.

The removal of the two major inadequacies of shaking table testing now made possible a number of new research topics on shaking tables.

At this stage, the shaking table at CEA Saclay and the reaction wall facility at JRC Ispra joined the group, the latter employing MCS to change pseudodynamic into continuous pseudodynamic testing, thereby removing the strain-rate effect in reaction wall testing. The six partners received three EC-funded contracts for research into the following topics:-

1 The ability to conduct tests in the non-linear range, 2 Substructuring in shaking tables, 3 The use of several shaking tables acting together - multiple "" support input, 4 Standards to be used in Qualification tests, 5 Complementary use of shaking tables and reaction walls, 6 Continuous non-linear testing at reaction walls.

The last of the three research contracts had the title 'New Fields of Research in Earthquake Engineering (NEFOREEE), and it is the conclusions from this that will be presented in the five papers of this Special Technical Session.

### NEFOREEE - PERFORMANCE BENCHMARK OF THREE MAJOR EUROPEAN SHAKING TABLES – ID 110

*J. C. Queval, CEA, France*
*R. Bairrao, LNEC, Portugal*
*P. Caridys, NTUA, Greece*

Previous studies within former European Consortia of Earthquake Shaking Tables, have investigated and compared how well the different shaking tables of these consortia could execute the same task using identical elastic test pieces. It has resulted in a control enhancement at all the facilities. Being then necessary that similar comparison tests be developed with extension to non-linear behavior, the largest possible specimen, specifically designed for that purpose, was built and tested on three very different shaking tables. This test specimen was designed to reproduce the global non-linear behavior of a concrete building while being damaged during an earthquake, concerning a typical global stiffness reduction. This system, being able to simulate a sudden collapse or a progressive degradation, can reproduce, in a repetitive and accurate way, the same non-linear conditions. In the present paper the design of the test specimen is discussed and the results of the tests are presented.

Keywords: Shaking tables - Controllers.

### TESTING PERFORMANCE BENCHMARK FOR SHAKING TABLES AND REACTION WALLS WITHIN THE NEFOREEE PROJECT – ID 303

*F. J. Molina, JRC, European Commission, IPSC, ELSA Laboratory, Italy*
*R. Bairrao, LNEC/DE/NESDE, Portugal*
*T. Blakeborough, Dept of Engineering Science, UK*
*O. Bursi, University of Trento, Italy*
*D. Tirelli, JRC, European Commission, IPSC, ELSA Laboratory, Italy*
*G. E. Magonette, JRC, European Commission, IPSC, ELSA Laboratory, Italy*
*H. Mouzakis, NTUA, Laboratory for Earthquake Engineering, Greece*
*M. S. Williams, Dept of Engineering Science, UK*

Within the NEFOREEE project (New Fields of Research in Earthquake Engineering Experimentation) funded by the European Commission, a one-storey one-bay-by-one-bay steel frame model was tested at different shaking tables and pseudodynamic (PsD) facilities within the EU. The same specified unidirectional input was introduced in real time at the shaking tables or pseudodynamically at the other facilities. The specimens used at both kinds of facilities have the same characteristics and size (3m of length and height by 2.7m of width, with a rigid mass of 8250 kg) and were tested for several retrofitting configurations by means of added dissipator devices. However, at one of the facilities, the PsD tests were conducted by using only a part of the physical model thanks to the substructuring techniques. At the unprotected configuration the specimen behaviour is very linear but its damping is very low, which puts in evidence any alteration introduced by the testing methods such as control delays in the PsD method or spurious rocking on the shaking table. With non-linear dissipator devices, those deficiencies may be hidden by the large damping developed at the specimen, but an appropriate strain-rate-effect compensation technique is necessary within the PsD method. In a similar way, that non linearity may impose limitations as well on the compensation techniques based on linear filtering of the reference signal and traditionally used at the shaking tables. This paper presents the current stage of these studies including results of the performed tests in both kinds of facilities. The mainresults in the developments of the continuous PsD method with substructuring are also reported.

### NEFOREEE TASKS 4 AND 5: AUTOMATIC CONTROL OF DYNAMICALLY SUBSTRUCTURED TEST SYSTEMS AND MULTIPLE SUPPORT INPUT – ID 1809

*D. Stoten, University of Bristol, UK*
*A. Crewe, University of Bristol, UK*

This paper describes the developments and achievements on the automatic control, dynamic substructuring and multiple support input tasks in the NEFOREEE programme. In particular, we describe: (i) the controller software and hardware developments, based on the use of dSPACE; (ii) the synthesis of a new adaptive algorithm for the control of dynamically substructured systems; and (iii) a series of tests on servohydraulic test-beds and a shaking-table in order to validate the new controller and substructuring methodology. The main conclusion of this work is that a modified form of the adaptive minimal control synthesis (MCS) algorithm [Stoten, 1989] will yield near-perfect synchronisation of the substructured components, when its initial conditions are set to the so-called Erzberger gains.

### RELIABILITY OF QUALIFICATION TESTS OF INDUSTRIAL PRODUCTS USING SHAKING TABLES – ID 795

*G. Franchioni, CESI Ricerca SpA, Italy*
*M. Fratelli, CESI SpA, Italy*
*R. Fregonese, CESI Ricerca SpA, Italy*

This paper deals with the issue of the reliability of the seismic qualification of industrial products using modern shaking tables and describes the campaign of tests carried out, in order to investigate the influence of different aspects (testing methods and parameters) affecting the entire qualification process. A first class of problems concerns the adequacy of the reference documents (standards and recommendations) for products qualification, particularly in the case of the seismic and dynamic testing, in relation to the technical difficulties of assessing the structural and functional behaviour of the specimen and to the use of sophisticated testing equipment and procedures. A second class of problems arises when no standards or recommendations exist at all or there is a wide dispersion of qualification approaches, sometimes even invented by single Producers: the main effect is the difficulty of comparing the results of the qualification process and of objectively assessing the performances of products, so vanishing the fundamental role of the experimentation. A final aspect affecting the reliability of the qualification process deals with the experimental approach. Two problems have to be especially pointed out: the first one concerns the uniformity of the approaches in the various laboratories, reflecting different knowledge and schools and generally leading to different testing procedures. The second aspect is related to the available technologies, shaking tables for earthquake replication and associated control systems. The present paper summarises the works carried out at CESI Laboratory under the FP5 Project NEFOREEE, aimed at exploring the above listed problems and trying to quantify, through selected and representative tests, their incidence on the qualification process. The following aspects were mainly addressed, because of their great influence on the reliability of the experiments: control of the spurious motions of the shaking table; assessment of control strategies; dynamic characterisation tests; input definition.

## STS E8: Shaking Table Facilities and Testing for Advancement of Earthquake Engineering

Monday 15:30 - 17:00 – Room 22

### SHAKING TABLE AND ACTIVITIES AT E-DEFENSE – ID 356

*K. Kajiwara, National Research Institute for Earth Science and, Japan*
*M. Sato, National Research Institute for Earth Science and, Japan*
*M. Nakashima, National Research Institute for Earth Science and, Japan*

Over the last ten years, the National Research Institute for Earth Science and Disaster prevention (NIED) had been constructing a shaking table facility, known as E-Defense. E-Defense was completed in March 2005, and its operation started in April 2005. The Hyogo Earthquake Engineering Research Center was established on October 1, 2004, to manage research projects using E-Defense and to operate as well as to maintain the facility. E-Defense has the unique capacity to experiment with life-size buildings and infrastructural systems in real earthquake conditions, and stands as a tool of ultimate verification. With this feature, E-Defense should help expedite the transfer of various research outputs into the practice of earthquake disaster mitigation. E-Defense located in a city called Miki on the north of Kobe City. The heart of the facility is a " j u m b o - s i z e d " shaking table in the center of the site. The table is attached to five actuators in each horizontal direction and supported by fourteen actuators installed vertically underneath the table. The table is 20 meters by 15 meters in the plan dimension. It can accommodate a specimen up to a weight of 12 MN (1,200 metric ton). The unique feature of the table is that can produce shaking of a velocity of two meters per second and a displacement of one meter in the two horizontal directions simultaneously. As far as the capacity is concerned, the table owned by E-Defense appears to be the largest shaking table in the world. Construction of E-Defense was nearly complete in the fall of 2004, and since that time a series of tests on performance calibration have been conducted, without specimens in the first phase and with real-size specimens in the second phase.

### NEES-UCSD SHAKE TABLE AND TESTING ACTIVITIES AT THE UNIVERSITY OF CALIFORNIA, SAN DIEGO – ID 1474

*J. Conte, UCSD, United States*
*J. I. Restrepo, UCSD, United States*
*J. E. Luco, UCSD, United States*

The new large high-performance outdoor shake table (LHPOST) at the University of California, San Diego, is one of the 15 equipment sites of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) funded by the United States National Science Foundation (NSF). Funding from NSF to build the shake table was awarded in October 2002. The shake table was commissioned in September 2004. Although the LHPOST currently has a single DOF capability, it has been fully designed for six DOFs. The LHPOST, acting in combination with adjacent equipment and facilities including a large laminar soil shear box and two refillable soil pits, provides a unique facility for large-scale seismic testing of soil-foundation-structure interaction systems. The facility is being used to conduct large- and full-scale testing to investigate structural and/or geotechnical seismic performance issues that cannot readily be extrapolated from testing at smaller scale, or under quasi-static or pseudo-dynamic conditions, including performance under near field ground motions. Such experiments present unique opportunities to develop, calibrate, and validate predictive computational tools in earthquake engineering. This paper will focus on design issues and technical specifications of the LHPOST, as well as results from commissioning and detailed characterization tests. The paper will also describe possible uses of the table and will briefly discuss the results of a test programme on a seven-story building slice built at full-scale, which was completed in early 2006.

### SHAKING TABLE AND RESEARCH ACTIVITIES AT EUCENTRE PAVIA – ID 1099

*A. Pavese, DMS - Università di Pavia, Italy*
*G. M. Calvi, DMS - Università di Pavia, Italy*
*F. Dacarro, EUCENTRE, Italy*

This paper provides a detailed description of the experimental facilities recently installed at EUCENTRE, European Centre for Training and Research in Earthquake Engineering (Pavia, Italy). EUCENTRE was established in the 2003 with the main financial support of the Italian National Civil Protection Department and those of the Italian National Institute for Geophysics and Volcanic Studies, the University of Pavia and the Institute for Advanced Study of Pavia. The testing facilities at EUCENTRE consist of a large uniaxial high performance shaking table, two strong walls and an upcoming bearing tester. The seismic shake table has a platen of 5.6 by 7 meters and is powered by a single innovative MTS 28 MPa hydraulic actuator, the system can provide a maximum horizontal displacements of ±500 mm, peak velocity of 2.2 m/sec, peak acceleration of 6 g, maximum force of 2100 kN, overturning moment of 4000 kNm, and can perform tests on specimens of 140 ton. The structural testing system for pseudo-static and pseudo-dynamic applications consist of two L-shaped walls 12 m height, 2.4 m thickness, a testing area of 140 m2 (strong floor) and 10 static and dynamic actuators which capacities range from 250 to 2500 kN. The shake table capabilities will be extended with the installation of a new strong frame and a new system of actuators able to apply and control vertical loads up to 50 GN to be used to test a large variety of bearings under seismic loading. The oil flow rate will be increased 16000 lpm to sustain the new performance requirements. The paper provides also a description of the activity performed to attain the optimal calibration of the system and the research programs which will be carried out in the next years which include test on full scale r.c. and masonry buildings and scaled bridge piers

### VALUES OF LARGE SHAKING TABLE STRUCTURAL TESTS – ID 1104

*G. M. Calvi, DMS - Università di Pavia, Italy*
*M. Nakashima, Kyoto University, Japan*
*A. Pavese, DMS - Università di Pavia, Italy*

The value of experimental investigations has proven itself over the years as a most valuable means for engineers to assess the response of structures when subjected to seismic actions. Among the variety of methods available the real-time fully dynamic is considered the only currently available means of truly reproducing the dynamic effects that earthquakes impose on structures. However, hydraulic power limitations in the vast majority of shaking tables available in the past impose the requirement for the use of reduced scale specimens. This, in turn, introduces difficulties and uncertainty in the interpretation of experimental results, since it has yet to be established what is the minimum scale or minimum portion of a building system that can be tested to reflect strength and deformation properties of actual buildings. Therefore, the need for building large and powerful dynamic facilities, capable of testing up to failure full-scale models, has become clear. After the recent worldwide development of the last generation of shake table facilities for seismic simulation characterized by large platen size, high performances and sophisticated hardware and software control, the extension of this valuable testing technique to full scale prototypes seem to be closer and real. The paper attempts to critically examine from the structural engineers perspective the performances of the shake tables today available and to compare them with the requirements when assessing structures response during seismic loading. Emphasis is given to several aspects related to earthquake effects simulation using prototypes which represent in every application a simplification of the real world. Prototype response reliability is discussed when size effects are considered mainly when the non linear behaviour of the prototype is achieved.

The response modification due to the rate effect and to the mass distribution assumed are also discussed and referred to physical properties of the table and performances

### INTERNATIONAL COOPERATION, EXPERIENCES, VALUES, CHANCES – ID 1538

*A. Pinto, Joint Research Centre, Italy*
*P. Pegon, Joint Research Centre, Italy*

In order to meet the objectives of earthquake risk mitigation worldwide and progress towards performance based seismic design and assessment, there is also a need for experimental facilities capable of handling complex structures and systems, to understand real effects of phenomena like soil-structure interaction and to combine physical and numerical testing online and offline in a sort of 'real-virtual testing environment' where local and global, point and field measuring/visualization systems and corresponding processing can provide detailed information on demands and consequences. Furthermore, there is a need for international co-operation in order to better use the existing facilities, to build on synergies from complementary facilities and expertise, to exploit widely the data from the various experimental campaigns reaching education, research, profession and policy objectives.

NEES (USA) represents a pioneering initiative on the creation of a country-wide network of experimental facilities and their users aiming at a collaborative research approach for the EE community. The E-Defense facility (Japan) hosts the largest shaking-table in the world, capable of testing large structures up to collapse. In Europe, there is experience of collaboration between EE facilities and a new large shaking-table was recently constructed in Italy. In addition, JRC-ELSA has made substantial progress on the implementation of PSD testing with substructuring.

The paper reviews the main features of the existing facilities and research programmes, discusses the premises of a worldwide co-operation on earthquake testing and simulation with a focus on standardization of data allowing for exchange between facilities as well as for effective data exploitation by the user communities. The objective is to increase the value of testing ("...we must converge and collaborate....the barrier is the lack of strategic vision for shared resources") and to catalyze real inter-laboratory collaboration and exchange of expertise in view of the growing experimental complexity.

## STS E9: Analysis and Design of RC Frames with Masonry Infills

Friday 10:45 - 12:15 – Room 2

### SEISMIC DESIGN ISSUES FOR MASONRY-INFILLED FRAMES – ID 313

*M. Fardis, University of Patras, Greece*

Field experience and analytical/experimental research demonstrate the overall beneficial effect of masonry infills on the seismic performance of buildings, especially when the structure has little engineered earthquake resistance. If they are effectively confined by the frame, infill panels reduce, through their in-plane stiffness, storey drift demands, increase, through their in-plane strength, storey lateral force resistance and contribute, through their hysteresis, to the global energy dissipation capacity. EC8-Part 1 considers non-structural infills as a second line of defence and a source of overstrength for new buildings and does not reduce the seismic action effects for the design of the structure due to the beneficial effects of infills. EC8-Part 3 does not include provisions to help the designer account for the infills in the assessment of existing buildings and in the design of their retrofitting. If the contribution of masonry infills to lateral strength/stiffness is large relative to that of the structure itself, the infills may override the seismic design and render ineffective the designer's effort to control the inelastic response by spreading inelastic deformation demands throughout the structure: ∼ collapse of integrity of ground storey infills produces a soft storey; ∼ infills non-uniformly distributed in plan or elevation concentrate inelastic deformation demands in part of the building; ∼ infills may cause pre-emptive brittle failures of frame menbers. EC8-Part 1 provides guidance or mandatory rules against such local or global adverse effects. There are still open issues regarding the rational use of masonry infills in seismic design, assessment or retrofitting: ∼ List of key material properties for the strength, stiffness and deformation capacity of masonry infills and default values for them; ∼ Simple rules for the strength, stiffness and deformation capacity of infill panels with openings. ∼ Guidance for upgrading the infills into engineered structural components in seismic retrofitting.

### SOME CONTRIBUTIONS OF PHYSICAL AND NUMERICAL MODELLING TO THE ASSESSMENT OF EXISTING MASONRY INFILLED RC FRAMES UNDER EXTREME LOADING – ID 370

*D. Combescure, CEA Saclay, France*

Numerical modeling and experimental works represent unavoidable tools for predicting the effects of the unreinforced masonry infills on the global and local behaviour of reinforced concrete frames under both in-plane and out-of-plane horizontal dynamic actions. These analyses usually in the non linear range are particularly necessary for the assessment of existing reinforced concrete structures supporting horizontal dynamic loading induced by earthquake and also by internal and external explosion (caused by failure of pressurized pipes or vessels, hydrogen explosion, external aggression...). In the present paper, examples of application of global and refined non linear models to the analysis of structures tested in laboratories under static, pseudo-static or dynamic loading will be given showing the difficulties to be solved during the non linear analysis nowadays used extensively by structural engineers. Refined non linear modelling is very useful to perform predictive calculations on structures with various geometries and material characteristics. Complex effects such as the effect of openings, the interaction between infill and frame can also be studied. Nevertheless the cost of the computations does not allow extensive or dynamic studies. Non linear diagonal strut and beam models represent the unique strategy for the analysis of complete civil engineering structures under extreme dynamic loading. The most critical step becomes the identification of parameters taking into account the experimental results available in literature but also the material and structure variability. The paper will include some results of parametrical studies performed with refined non linear models in order to identify the main properties of the equivalent diagonal struts -stiffness and strength- and to assess the shear forces induced by masonry infill in the RC frame which may conduct to a brittle failure of the reinforced concrete members.

### SIMPLIFIED SEISMIC ASSESSMENT OF INFILLED REINFORCED CONCRETE FRAMES – ID 888

*M. Dolsek, University of Ljubljana, Slovenia*
*P. Fajfar, University of Ljubljana, Slovenia*

A relatively simple nonlinear seismic analysis method based on pushover analysis and inelastic spectrum approach (N2) has been developed at University of Ljubljana and implemented in the European standard Eurocode 8. The method was recently extended in order to make it applicable to infilled reinforced concrete frames. Compared to the basic method implemented in Eurocode 8 two important differences apply. A multi-linear idealization of the pushover curve, which takes into account the strength degradation which occurs after the infill fails, and a specific R-$\mu$-T relation have to be used for the determination of the displacement demand for a given seismic intensity or the determination of the seismic intensity corresponding to a selected limit state. The relation between the displacement demand and seismic intensity can be visualised with the IN2 curve which is a simple alternative to the summarized IDA curve.

In the paper the method is summarized and applied for seismic assessment of a 4-storey infilled reinforced concrete frame, which

was pseudo-dynamically tested in full-scale in the ELSA laboratory in ISPRA. The most common analytical modelling technique, which employs compressive diagonal struts for modelling of masonry infill, and one-component lumped plasticity elements for modelling of beams and columns flexural behaviour, was applied. The model of the infill frame and the model of the bare frame were validated by the test results. The OpenSees program was used for all analyses performed in the study. The proposed method for seismic analysis was used to determine seismic intensities, which correspond to different limit states. In addition to the infilled frame, the bare frame was also analysed. The results indicate that the seismic intensity corresponding to the near collapse limit state is higher for the infilled frame. However, the plastic mechanism in the infill frame is less favourable than that in the bare frame.

## STS E10: By How Much Does the Natural Frequency of Structures Decrease During Seismic Response ?

Thursday 15:30 - 17:00 – Room 4

### STATE-OF-THE-KNOWLEDGE ON THE PERIOD ELONGATION OF RC BUILDINGS DURING STRONG GROUND SHAKING – ID 1535

*G. M. Calvi, University of Pavia, Italy*
*R. Pinho, University of Pavia, Italy*
*H. Crowley, ROSE School, Italy*

This paper presents the case for the significant elongation of the period of vibration of reinforced concrete buildings during strong ground shaking due to earthquakes. This viewpoint is substantiated by the results of experimental tests on RC buildings, wherein a large increase in the period of vibration is observed during ground shaking. The increase in the fundamental period is obviously dependent on the level of shaking and the associated extent of non-linearity that is attained within the structure. Analytical models which replicate the results of the experimental tests are introduced and additional studies on the elongation of the period during seismic action are presented.

### COMPARISON OF THE DYNAMIC PARAMETERS EXTRACTED FROM WEAK, MODERATE AND STRONG BUILDING MOTION – ID 1021

*F. Dunand, LGIT, France*
*P. Gueguen, LGIT, France*
*P. Y. Bard, LGIT, France*
*M. Celebi, USGS, United States*

Ambient vibration analysis is proposed as an alternative way to inspect buildings before or after an earthquake. This fast and low-cost method is well-adapted to large-scale studies for which a large amount of buildings has to be checked. One of the most common critics usually done on the use of ambient vibrations in structures is the very low level of vibrations. Because of the low amplitude range of the ambient vibration (PGA<10-5g), dynamic characteristics obtained from weak-motion are generally expected to be significantly different from those obtained using strong-motion (PGA>0.1g). This difference has been already observed essentially on frequency and on damping values, in case of forcing vibrations and strong grou nd motion. These variations are generally attributed (1) to the non-linear behaviour in the structure material; (2) to the slip of the connections ; (3) to the interaction between structural and non-structural elements; and (4) to a possible non-linear soil-structure interaction effect. The objective of this paper is to present a comparison of the structural dynamic characteristics deduced from strong, moderate and weak motion rec ordings for a set of twelve Californian buildings and four European buildings. The present study differs from numerous previous investigations in two aspects: (a) the number of compared building is larger; and (b) for two buildings, more than 10 earthquakes records are available, which allows to investigate the dependence of dynamic characteristics with shaking intensity.

## STS E11-I: Petrochemical Facilities and Large LNG Storage Tanks

Thursday 10:45 - 12:15 – Room 23

### BENEFITS OF SEISMIC ISOLATION FOR LNG TANKS – ID 1083

*M. Crespo, PRINCIPIA, Spain*
*S. Omnes, PRINCIPIA, Spain*
*J. Marti, PRINCIPIA, Spain*

The paper discusses the seismic environments in which LNG tanks need not, may, and must be seismically isolated, as well as the associated costs and benefits when both alternatives are reasonable options. The problems that a gradually increasing seismic demand may cause in an LNG tank are reviewed first: they include greater demands in the inner tank, problems associated with corner uplift and elephant's foot buckling, gross sliding of the inner tank, thickness requirements beyond the weldable limit and global uplift of the inner tank. Some of these problems cause extra costs while others make the construction impossible. The acceleration demands at which each of these problems are expected to arise are quantified. Although the work includes conventional and seismically isolated versions of two existing tank configurations (60,000 and 100,000 m3 capacity) it concentrates on a 160,000 m3 tank, which is more representative of current tendencies; for the latter, both a surface slab and a pile foundation are considered. The feasibility of conventional and seismically isolated designs is examined as a function of the design acceleration.

Some assumptions are then introduced for the costs of the required features and materials, leading to costs estimates for dealing with the seismic threat for each seismic environment and tank design option. Over the range of accelerations that allow both isolated and non-isolated designs, approximate cost comparisons are established. The study was carried out within the framework of the EC-funded INDEPTH project.

### IMPROVEMENT IN DAMPING CHARACTERISTICS OF SEISMIC ISOLATED TANKS USING BAFFLES – ID 947

*A. Maleki, IIEES, Iran (Islamic Republic Of)*
*M. Ziyaeifar, IIEES, Iran (Islamic Republic Of)*

The effectiveness of baffles in reducing earthquake responses of Base Isolated cylindrical liquid storage tanks is investigated in this work. Baffles are considered as an indispensable part of moving liquid containers, however, their usage in Liquid Storage tanks subjected to earthquake loads are limited. Rationally, in such cases, baffle adds to the damping ratio of the sloshing mode of the system and causes much lower structural response. To study the effects of using baffles in Base Isolated Liquid Storage tanks, at first, damping potential of conical shaped baffles in circular tanks is estimated. In this regard, a methodology based on Tank Body Spectra is developed in which, higher sloshing amplitude and relative velocity with respect to baffles in Base Isolated tanks are taken into consideration. The result indicates that, while damping ratio of sloshing mode in a normal LS tank is around 0.5%, using baffles can easily push this ratio to about 10%. To be able to assess the effects of damping ratio improvement in general structural response of the system, a multi degree of freedom 2D simplified model is proposed. The model can represent distribution of structural responses along the height of the system. The accuracy of the model is verified through FEM analyses. Time integration analyses on the simplified model for different types of LS tanks subjected to a series of earthquake records have been carried out. The result of analyses shows that such enhancement on damping characteristics

of LS tanks can eventually reduce the level of structural response of the system to more than 6 percent on average.

### BASE ISOLATED LNG TANKS: SEISMIC ANALYSES AND COMPARISON STUDIES – ID 1128

*V. Gregoriou, University of Patras, Greece*
*S. Tsinopoulos, University of Patras, Greece*
*D. Karabalis, University of Patras, Greece*

The seismic response of two typical liquefied natural gas (LNG) tanks isolated at their base level by rubber bearings is investigated. The problem is solved numerically by means of detailed finite element models, taking into account fluid-structure interaction effects. Two types of bearings are investigated: high damping rubber bearings and lead core rubber bearings. The bearings are modeled as non-linear springs with the force-displacement relationships derived by fitting appropriate analytical curves to experimental data. The seismic excitation considered is an artificial accelerogram compatible with the Eurocode 8 provisions. Results concerning base shear force, sloshing vertical displacement and deflection of the inner steel container are presented. In order to measure the effectiveness of the isolation systems, percentage reductions of the peak response of all mentioned quantities are calculated using the non-isolated tank as reference. The research has been performed in the framework of the project INDEPTH (Development of INnovative DEvices for Seismic Protection of PeTrocHemical Facilities), supported by the Environment and Sustainable Development Programme of the European Commission Research Directorate General (Contract EVG1-CT-2002-00065).

### SEISMIC ISOLATION OF SPHERES AT PETROCHEMICAL FACILITIES – ID 1009

*G. Bergamo, CESI, Italy*
*M. G. Castellano, FIP Industriale, Italy*
*F. Gatti, CESI, Italy*
*A. Poggianti, ENEA, Italy*
*P. Summers, MMI Engineering, United States*

Base isolation has not yet been used as a means of mitigating seismic hazards for spheres at petrochemical facilities, despite their often-times high seismic vulnerability and associated risk due to their hazardous contents. This research, carried out within the framework of the EC-funded INDEPTH project, was aimed at showing the benefit of seismic isolation for both new and existing spheres. A number of parametric non-linear time-history analyses have been carried out on a simplified Housner model of a typical sphere isolated with different types of isolation systems, and with different target isolation periods, in order to quantify the response reduction due to seismic isolation, and to select the optimal isolation system. The selected isolation system was reproduced in a mock-up sphere subjected to shaking table tests. The mock-up was designed to reproduce the same fundamental frequency of the actual sphere. The tests were performed with two different accelerograms, at different PGA values up to 0.4 g, with three different filling levels (empty tank, 20% filled and 90% filled), both with and without seismic isolation, and with different seismic isolation systems. The results obtained with high damping rubber bearings and lead rubber bearings are reported herein. A comparison between conventional and seismically isolated design was also carried out, on the basis of an analytical assessment of sphere vulnerability for gradually increasing seismic demand (PGA values ranging from 0.1g to 0.8g). Two performance objectives for conventional design are included in the assessment: one representative of a typical code-based design approach, allowing damage, and the other whereby a performance objective of minimal damage is specified. This latter approach permits a direct cost comparison with the isolated design, showing that for design PGA values higher than 0.25g, seismic isolation permits the tank to remain relatively undamaged at lower costs than for conventional design.

### SEISMIC RETROFIT OF SPHERES USING ENERGY-DISSIPATING BRACES – ID 1001

*A. Poggianti, ENEA, Italy*
*M. G. Castellano, FIP Industriale, Italy*
*P. Summers, MMI Engineering, United States*

The paper describes seismic retrofit and parametric numerical analysis of an existing sphere, selected as representative of many existing spheres found in petrochemical facilities. The sphere has a 20 m diameter and is supported on 11 columns with conventional tension-only braces as the lateral force resisting system. An innovative retrofit design scheme has been considered, utilizing energy-dissipating braces to substitute for the existing braces. Two types of dissipative braces have been proposed, using as energy dissipation devices non-linear fluid viscous dampers or buckling-restrained braces. Non-linear time history analyses were carried out, using as input artificial accelerograms compatible with EC8 spectra, with PGA=0.4 g. The parameters considered were those characterizing the constitutive law of the dampers, i.e., the viscous constant for the viscous dampers (the exponent of the velocity was kept constant, equal to 0.1), as well as the elastic stiffness and the yield force for the buckling-restrained dampers (the ratio of post-elastic to elastic stiffness was not considered, since the results of preliminary analyses had shown that the structural response is not sensitive to this parameter). The benefits of the proposed seismic retrofit schemes with steel-hysteretic or viscous dampers are shown in comparison with a conventional retrofit design approach, entailing the substitution of existing tension-only braces with stiffer braces able to work in compression, and with retrofit by seismic isolation. Although the latter is also effective, the retrofit using dissipative braces is easier to be implemented than seismic isolation, and is able to realize a reduction in the structural response parameters on the same order, thus allowing the sphere to remain undamaged at the target retrofit PGA of 0.4 g. This study was performed within the framework of the EC-funded INDEPTH project.

## STS E11-II: Petrochemical Facilities and Large LNG Storage Tanks

Thursday 13:30 - 15:00 – Room 23

### SEISMIC VULNERABILITY ANALYSES OF CYLINDRICAL STEEL ABOVE GROUND TANKS IN AN OIL REFINERY COMPLEX – ID 572

*N. Hosseinzadeh, IIEES, Iran (Islamic Republic Of)*
*A. Valaee, SRC, Iran (Islamic Republic Of)*

Cylindrical steel above ground tanks extensively used in oil refinery complexes and oil depots in Iran. Average capacity of this kind of tanks is about 20,000 kl with diameter of about 40 m and height of about14 m, which built on the compacted sand. Experiences in Japan, U.S. and turkey show that these tanks are very vulnerable to strong earthquake ground motions. Failure modes such as settlement, shell buckling, Roof Damage and overturning are the main causes of extensive material leakage and fire immediately after an earthquake. In this paper 112 tanks in an oil refinery complex are categorized into 20 types in order to seismic vulnerability evaluation and retrofit design. International documented references such as API650 and ASCE standards and finite element analyses used in this study. Important parameters such as Liquid sloshing, tank bottom uplift and liquid-shell interaction considered in dynamic analyses. Site-specific spectrum with maximum acceleration of 0.25g, as well as site compatible earthquakes records considered as input motions. The results show that about 40 percent of the existing tanks are vulnerable and require retrofitting or strengthening. It can be noted that the aspect ratio (height to diameter) is an important parameter in seismic vulnerability of studied oil tanks.

### RAPID SEISMIC SAFETY EVALUATION OF EXISTING LIQUID STORAGE TANKS – ID 415

*S. Eshghi, IIEES, Iran (Islamic Republic Of)*
*M. Seyed Razzaghi, IIEES, Iran (Islamic Republic Of)*

During the recent decades several damage suffered by cylindrical liquid storage tanks due to the earthquakes such as Anchorage, Alaska (1964) and Izmit, Turkey (1999) seismic events. Damage to liquid storage tanks in oil related industries not only cause direct losses but also may cause serious indirect social and economic impacts due to the work stoppage, environmental pollutions, etc. Thus the evaluation of seismic vulnerability of existing storage tanks in high risk zones is an important task. There are several approaches for rapid evaluating seismic vulnerability of existing facilities in different guidelines. Some of them are based on walk through inspection of the facilities and some others are based on seismic fragility curves. The objective of this study is to highlight the advantages and shortcomings of different approaches of vulnerability assessment of the on-ground cylindrical liquid storage tanks. In this paper, various approaches for rapid evaluation of seismic vulnerability of existing liquid storage tanks are presented and compare to each other and then the summary results of a detailed seismic vulnerability assessment of a two large tank farms in an oil refinery in a high seismic city of Iran are presented. Results of this assessment are compared to the developed fragility curves such as HAZUS and ATC-13 seismic fragility curves. Finally numerical analyses were conducted for some of the tanks and the accuracy of different rapid vulnerability assessment methods is discussed. The results of this study shows that there is a possibility to generate a family of seismic fragility curves with inclusion of the effects of factors such as height-to-diameter ratio, the volume of contained liquid and other important parameters. This fragility curve can be used in a rapid safety evaluation of exiting oil tanks.

### SIMULATION OF SLOSHING EFFECTS IN LIQUID-CONTAINMENT TANKS – ID 1559

*S. A. Kilic, Bogazici University, Turkey*

The Marmara earthquake of 17 August 1999 caused extensive damage in industrial facilities in Turkey. Part of the damage occurred at the Tupras oil refinery situated near the epicentral region. Floating-roof tanks containing liquid naphtha caught fire during the strong shaking. Fixed-roof tanks sustained damage in terms of upper shell buckling and elephant-foot deformations at the base.

Finite element simulation of the fluid-structure interaction effects are presented in this paper for modeling the sloshing phenomenon for liquid-containment tanks. The ground motion records at the nearby Yarimca station are used for the dynamic analysis. The non-linear finite element code used in this study utilizes the explicit time integration scheme, which allows the dynamic movement of the liquid containment through the use of the Navier-Stokes equations, and its interaction with the shell structure of the tank walls through a coupling algorithm. Results are presented for the surface shape of the liquid at various stages of the ground motion, and the shell stresses on the tank walls due to sloshing. Suggestions are provided for improving tank design for seismic resistance.

### A SEISMIC ASSESSMENT METHOD FOR EQUIPMENT STRUCTURES CONSIDERING INTERACTION BETWEEN A TOWER AND STRUCTURES – ID 952

*M. Oshima, Chiyoda Advanced Solutions Corporation, Japan*
*T. Kase, Chiyoda Advanced Solutions Corporation, Japan*

Basically plant facilities such as refineries are continued comprehensive systems composed of towers, piping, and their supporting structures, etc., and simple methods of seismic design have been devised for the facilities. Although the levels of design ground motions tend to become larger, and evaluated items tend to become more detail and to increase in number, because the maximum response level of ground motion records become larger and new damage modes often arise whenever the big seismic events happen. In Japan, considerable plant facilities exist and the level of design seismic ground motions are the highest level in the world. So the owners of the facilities are required to mitigate the seismic risk of existing facilities of continued use for the general public living in the vicinity with the minimizing the occurrence of seismic damages. Concerning equipment structures of towers supported by skirts, seismic design of their foundations is very simple, if they are designed using the method of their code. But in cases that some towers or structures are set on a equipment structure, the number of the loading cases increases and seismic design became more complicated. Furthermore, new design will be able to be simple using the design with safety margin, but the seismic assessment for existing facilities is required to be devised individually in order to evaluate their existing seismic performance adequately. In this paper, a facility consisted of a tower, its surrounding frame structure, piping and a equipment structure is studied. To obtain the effect of interaction among them, parametric studies are performed to assess the interaction effect of response considering their ratio of fundamental frequencies and weight. The goal of this study is to make the information to obtain closer estimation of response sensitivity of their interaction at design stages or at seismic assessment stages.

### SLOSHING LOADS IN TANKS WITH INSUFFICIENT FREEBOARD – ID 111

*P. Malhotra, FM Global, United States*

Earthquake induced sloshing in tanks is caused by long-period ground motions which attenuate slowly with distance. A minimum freeboard is needed to accommodate the sloshing waves. Since freeboard results in unused storage capacity, many tanks lack the required freeboard. As a result, sloshing waves impact the roof, generating additional forces on the roof and tank wall. Tanks have suffered damage due to sloshing waves, yet their effect is usually ignored in seismic design of tanks. This paper presents a simple method of estimating sloshing loads in flat, cone and dome roof tanks.

## STS E12: Joint IAEE-IASPEI Session on International Collaboration of Earth Science and Earthquake Engineering Professional Associations

Wednesday 10:45 - 12:15 – Room 15

No written contributions submitted to this session

## STS E13-I: LESSLOSS Project: General Assembly

Wednesday 09:15 - 10:15 – Room 2

No written contributions submitted to this session

## STS E13-II: LESSLOSS Project: General Assembly

Thursday 10:45 - 12:15 – Room 2

No written contributions submitted to this session

## SC-A 1-I: Archaeological and Historical Studies on the Earthquakes of the Past Centuries

Thursday 10:45 - 12:15 – Room 15

### THE EARTHQUAKES OF THE XIV AND XV CENTURIES IN CATALONIA (NE SPAIN) – ID 848

*C. Olivera, Institut Cartogràfic de Catalunya (ICC), Spain*
*E. Redondo, Institut cartogràfic de Catalunya (ICC), Spain*
*J. Lambert, Bureau de Recherches Géologiques et Minières (BRGM, France*
*A. Riera-Melis, Dep. Història Medieval, Universitat de Barcelona, Spain*
*A. Roca, Institut Cartogràfic de Catalunya (ICC), Spain*

In 1985 the Geological Survey of Catalonia started a project to compile a comprehensive catalogue of seismic activity in Catalonia in order to provide a correct evaluation of seismic hazard. The project concludes with the publication, in 2006, of a book that gathers the results of the interdisciplinary work carried out on the most important historical earthquakes in Catalonia, which took place in the XIV and XV centuries. One of the most prominent features of this monograph is that it provides a compilation of all the documentation concerning the earthquakes of the late medieval period. For the first time it has been possible to undertake a joint analysis of all the documentation of the earthquakes of the late medieval period in Catalonia and to evaluate these events using homogeneous criteria. Our evaluation of the earthquakes is a marked improvement on earlier studies in two respects: name and quality of the descriptions, and homogeneity. A catalogue of the earthquakes of the XIV and XV centuries has been compiled. From this catalogue it can be deduced that the earthquake with the greatest intensity, IX, occurred on 2 February 1428 and that its magnitude corresponds to the highest value Mw of 6.5. The second largest earthquake occurred on 3 March 1373, with a magnitude Mw of 6.2 and epicentral intensity of VIII-IX. Focal parameters of the 8 earthquakes with Io >VI are presented. These are the 2 events previously mentioned (1373, 1428), 5 events of the 1427 seismic sequence and another earthquake occurred in 1448.

### "HERE ARE LIONS": HUNTING FOR TRACES OF UNKNOWN EARTHQUAKES AROUND 15TH-16TH CENTURIES AD – ID 1967

*V. Castelli, INGV, Italy*
*R. Camassi, INGV, Italy*
*L. Postpischl, INGV, Italy*

In the last few years, the existence of several earthquakes (significant ones, some of them) still unknown to the current seismic catalogues has been discovered in the course of studies – particularly Italian ones - whose main goal was the systematic exploitation of serial historical sources. Contrarily to what it could be expected, most of these discoveries do not occur in the upper chronological reaches the historical seismic catalogues (i.e. in the Classical Antiquity or the Early Middle Ages) but – oddly enough – in a much nearer historical period, namely the 15th-16th centuries AD. In other words, there are some inklings suggesting that there could be a sort of "black hole" in the very middle of Italian seismic history, which the available knowledge, as summed up in the current catalogue is unable to fill adequately. Judging from the evidence that can be occasionally fished up, this vacuum is likely to have swallowed up not a few significant earthquakes. This study presents a set of case-histories concerning "unknown" damaging earthquakes whose existence is clearly attested by contemporary chronicles and diaries, trying to understand why their occurrence failed to attract the attention of the early hunters of Italian historical earthquakes whose output of traditional seismological compilations forms the backbone of the modern Italian parametric catalogues, and attempting a preliminary evaluation of the likely relevance of the "new" data for an evaluation of the level of completeness of the current Italian catalogue.

### A REVISION OF THE EFFECTS OF THE 1356 BASEL EARTHQUAKE – ID 1296

*D. Fäh, Swiss Seismological Service ETH, Switzerland*
*M. Gisler, Swiss Seismological Service ETH, Switzerland*

**Interdisciplinary project working group (Dagmar Bargetzi, Stefan Fritsche, Bernhard Jaggi, Philipp Kästli, Thomas Lutz, Virgilio Masciadri, Christoph Matt, Dieter Mayer-Rosa, Dorothee Rippmann, Gabriela Schwarz-Zanetti, Jürg Tauber, Thomas Wenk)

The 1356 Basel earthquake is the largest known seismic event in the northern Alpine region. To date this event has been studied mainly using historical information, even though the database was small and difficult to interpret. A current project at the Swiss Seismological Service in Zurich seeks to look into the event with an interdisciplinary approach, integrating historical, seismological, archaeological, paleoseismic, and engineering techniques. The project aims at compiling all information concerning the 1356 Basel earthquake and quantifying the impact and size of the event. Investigation of the historical data and its interpretation is focused on the entire damage field. Archaeological research on the other hand concentrates mainly on the city of Basel, seeking to collect information of particular buildings still existing today (some of them showing minor damage only) in order to provide a picture of the potential damage. The project includes engineering investigations on particular buildings in order to estimate the level ground motion of the event. Detailed seismological investigations were performed in the last years; the possible seismic source was identified and estimates of site effects were mapped. Finally, paleoseismological findings in the area of Basel were reviewed and integrated in the study. In this contribution we present the settings and first outcomes of these investigations and discuss the problems and chances of an interdisciplinary approach.

### THE 1690-EARTHQUAKE OF VILLACH (CARINTHIA; AUSTRIA) - ASSESSMENT OF MACROSEISMIC INTENSITY BY THE EMS-98 – ID 1391

*G. Gangl, Inst. Meteorology and Geophysics, Univ. Vienna, Austria*
*W. Egger, Austria*

The intensity of the macroseismic scale (EMS98) of the 1690 earthquake has been evaluated for the data points of the area of damage. The epicentre is north of the town of Villach in Carinthia with Io = 9 ±1. The paper describes the intensity assessment based on further inquiries and earlier data quoted below, and gives a list of intensity data points of the epicentral area. The earthquake is compared with the 1348 "Villach earthquake". The result is an important contribution to the earthquake hazard of Carinthia.

BARBANO.M S, D BELLETTATI, D SLEJKO. (1994) Sources of the study of Eastern Alps Earthquakes in the turn of the 17th century, Review of Historical Seismicity in Europe (RHISE) 1989-1993 in http:// emidius.mi.ingv.it/RHISE/ii_8bar/ii_8bar.html EISINGER U, R GUTDEUTSCH (1994) The Villach Earthquake of December 4th, 1690 in German Sources, Review of Historical Seismicity in Europe (RHISE) 1989-1993 in http:// emidius.mi.ingv.it/RHISE/ii_9eis/ii_9eis.html GANGL G.(2005) Starkbeben in Kärnten, Abstract zum Poster, Arbeitstagung der Geologischen Bundesanstalt in Gmünd, Kärnten

### THE JANUARY 9, 1906 DOBRA VODA EARTHQUAKE - A QUICK TEST OF RELIABILITY OF EXISTING MACROSEISMIC DATA – ID 1863

*C. Beauval, IRD - Geosciences Azur, France*
*P. Labak, Geophysical Institute, Slovak Academy of Sciences, Slovakia (Slovak Republic)*

Detailed complex investigation of historical earthquakes is a man-power and time consuming effort, which is possible to be

performed only for limited number of earthquakes. Therefore decision, which earthquake should be studied in detail is critical one, especially during the revision of larger macroseismic databases. Results of last investigation of the 1906 Dobra Voda earthquake are from the second half of 1970s. Therefore this earthquake might be the candidate for detailed investigation. Moreover, the January 9, 1906 Dobra Voda earthquake is the largest earthquake on the territory of Slovakia in the 20th century. It is also first instrumentally recorded earthquake with epicenter in Slovakia. This earthquake was investigated in detail by Rethly (1907). However, this paper includes results of the investigation, including the intensity estimation, rather than damage description for all localities. Later bulletins and isoseismal maps by Rethly (1952), Karnik et al. (1957) and Broucek in Atlas of isoseismal maps for Central and Eastern Europe refer to this work and does not indicate any additional investigation of earthquake effects. Therefore a quick damage and intensity estimation was made from existing primary sources. Results of this intensity estimation and estimations of Rethly, Karnik and Broucek and consequencies for further investigations are presented.

### HISTORICAL EARTHQUAKES IN LOWER AUSTRIA - SOURCE INVESTIGATION – ID 1684

*C. Hammerl, Institute of Meteorology and Geodynamics, Austria*

The pilot study "Historical Earthquakes in Styria", finished in 2002, served to complete the Austrian Earthquake Catalogue for the Province of Styria to gain a better image in terms of seismic hazard. It is planned to realize similar projects for the remaining eight Austrian provinces. Following this strategy, in 2003 the three years project "Historical Earthquakes in Lower Austria" was initiated. The project aimed at the investigation of a) so far unknown earthquakes, b) fake quakes and c) the correction of false catalogue entries.

To improve the seismic hazard assessment in Lower Austria the project focused mainly on: a) the research of gaps between 1000 and 1589 – no earthquakes are known in the relevant area – and completion of the catalogue for the period between 1600 and 1900, which comprises 18 earthquakes for this period and b) the restudy of damaging historical earthquakes in the area: Ebreichsdorf 1590 06 29 (I0=6); Neulengbach 1590 09 16 (I0=9); Wr.Neustadt 1668 08 27 (I0=7); Wr.Neustadt 1712 04 10 (I0=7); Baden/Wien 1734 01 06 (I0=6); Bad Fischau 1768 02 27 (I0=8); Wr.Neustadt 1841 07 13 (I0=7); Schottwien 1870 01 18 (I0=6); Eichgraben 1873 01 03 (I0=6-7); Grabensee 1875 06 12 (I0=5-6); Scheibbs 1876 07 17 (I0=7-8); Grabensee 1895 01 28 (I0=5-6); Gloggnitz 1885 09 22 (I0=6-7)

The results of the project are the translation, the interpretation and the documentation of the sources to enable the seismologist to use the texts for his interpretation. Further tables containing a description of the earthquake effects for each locality were carried out, as a basis for intensity estimation (IDP´s – intensity data points) at a later time. Until now the Austrian Earthquake catalogue didn't contain IDP´s, except for Styria, that's why this point is of particular importance.

State Government of Lower Austria funded the project – NC 59-2003, BD1-G-5100/9-2003.

## SC-A 1-II: Archaeological and Historical Studies on the Earthquakes of the Past Centuries

Thursday 13:30 - 15:00 – Room 15

### UNEARTHING EARTHQUAKES IN THE SIENESE CRETE: HOW WE IMPROVED THE CATALOGUE OF A LOW-SEISMICITY AREA – ID 837

*V. Castelli, INGV, Italy*
*F. Bernardini, INGV, Italy*

The Val d'Orcia is one of the latest Italian entries (2004) of the UNESCO World Heritage List. Its distinctive landscape of rolling chalk hills (the Crete), shaped in the 14th and 15th centuries to reflect an idealized model of good governance, and celebrated in the paintings of the Sienese school, has become an icon of the Renaissance that profoundly influenced the development of landscape thinking worldwide. Preserving the cultural wealth embodied in this corner of Tuscany is also a matter of assessing its seismic hazard correctly. As a first step toward this end, we revised the local seismic history. According to the current national catalogue, the Crete are a low-seismicity area intervening between two earthquake clusters centered on Siena (north) and Mount Amiata (south); the local earthquakes on record are very few, with middle to low epicentral intensities and none earlier than the second half of 17th century. However, the fortuitous discovery of a recent (1802) damaging earthquake unrecorded by any of the extant catalogues suggested that the current interpretation was more likely to derive from the little interest shown in the area having by previous studies rather than from an actual lack of data. By retrieving the memory of several forgotten damaging earthquakes (from 1449 onwards) and increasing the data set of the already known events, our study does significantly improve the Crete seismic history.

### A REAPPRAISAL OF THE SEISMIC HISTORY OF LOCRIS, CENTRAL GREECE – ID 1055

*S. Stiros, Dept. of Civil Engineering, Greece*
*S. Papageorgiou, Archaeological Service, Greece*

The earthquake history of Locris area in Central Greece is rather limited to reports of a 1894 earthquake associated with surface faulting and coastal subsidence, as well as to two or three historical earthquakes which occurred in the last 2,500 years. An examination of historical records reveals that reports usually assigned to the 426BC earthquake correspond to two different events, one in 426BC and a second probably several centuries later. Furthermore, a systematic study of churches in the wider meizoseismal zone of the 1894 earthquake revealed two clusters of church repair and construction, post-dating the 1544 and 1740 earthquakes known from historical reports. Church restoration and construction during this period were nearly impossible, as they required among others Sultan permission, and with the exception of certain known areas they reflected post-seismic recovery. These two clusters permit to define the meizoseismal areas of these two earthquakes, and in analogy to 19th-20th century earthquake in Greece to refine some of their parameters (epicenter, magnitude, etc.). A couple of other seismic events, deduced from ancient ruins bearing traces of seismic destruction, were also identified. These results are broadly consistent with results of palaeoseismological studies, based on stratigraphic analyses.

### SEISMIC HAZARD AND GREEK MONUMENTS – ID 1860

*N. Voulgaris, University of Athens, Greece*
*G. Kaviris, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*

Greece is a country of rich cultural heritage, that incorporates a large number of archeological (more than 50%), Byzantine and recent sites and monuments. Furthermore, Greece is characterized by the greatest seismicity in Europe, with almost half the seismic energy in Europe released in Greece. Large earthquakes occurred since the antiquity causing considerable damage, or destruction of cultural monuments. In an effort to evaluate the effects of seismic hazard to the cultural heritage of Greece, a detailed GIS implantation was created. Thus, the geographical distribution of Greek monuments reveals that their majority (more than 60%) lies on the second zone of the Greek Seismic Design Code (NEAK, 2004), corresponding to an acceleration value of 0.24g, while more than 50% are sited on soft soils, in contrast to 30% on rock. Greek monuments are also vulnerable to tsunamis caused by earthquakes. For example, ancient Helike, a classical Greek city, was buried in an alluvial plain on the southwest shores of the Gulf

of Corinth, due to a tsunami caused by a large earthquake on 373 b.C. The monument's eigenperiod may lead to conclusions related to damages caused by possible earthquakes. The contribution of seismology to the retrofitting of Greek monuments may involve the detailed estimation of the seismic hazard for each monument, microzonation in the vicinity of each monument and estimation of hazard due to tsunamis, liquefaction and landslides caused by earthquakes.

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### DEPOSITIONAL FACIES OF COLLAPSE UNITS IN ARCHAEOLOGY AND ARCHAEOSEISMOLOGICAL ISSUES – ID 1816

*F. Galadini, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

The collection of stratigraphic data from archaeological excavations is a typical practice of the archaeoseismological analysis. Usually, the archaeoseismological evidence consists of collapse units, made of destructed manufacts. However, due to the convergence of forms, not often the origin of the collapse can be defined. The analysis of the collapse units aimed at defining the depositional facies can reduce the number of the alternative causes of destruction and gives a picture of the destructive event, which can be integrated with the results of other in situ analyses. The study of the collapse stratigraphy derives from two main approaches, depending on the characteristics of the archaeological deposit: 1) the pure archaeological stratigraphic approach and 2) the interpretation of the stratigraphy mixing geological information with the archaeological one. In the procedure defined at point 1, the depositional facies of the collapse units is defined. For example, a typical collapse stratigraphy denouncing the abandonment of a site is made of (from bottom): i) layer of abandonment (generally small-sized particles); ii) small-sized portions of manufacts denouncing the lack of maintenance; iii) large-sized portions of walls, due to the final collapse of an edifice, etc... In order to interpret the depositional facies, the geoarchaeological practice becomes necessary when archaeological and geological deposits are associated (point 2 above reported). Typical examples are the collapses due to landsliding, e.g. remains of walls may be mixed with and overlain by fine-grained mass deposits in case of debris or mud flows responsible for the site destruction. Different cases of collapse stratigraphy will be proposed in order to define general "rules" which may be useful in the perspective of the archaeoseismological interpretation.

### GEOLOGICAL AND ARCHAEOLOGICAL EVIDENCE FOR ROMAN AGE FAULTING IN CENTRAL NORTHERN SICILY: POSSIBLE EFFECTS OF THE A.D. 361 EARTHQUAKE? – ID 1985

*G. Barreca, Dip. Scienze Geologiche Università, Italy*
*M. S. Barbano, Dip. Scienze Geologiche, Università, Italy*
*S. Carbone, Dip. Scienze Geologiche, Università, Italy*

According to historical and instrumental records, the southern flank of the Madonie Mts. (central northern Sicily) is characterised by only a few moderate earthquakes. We present results of recent field investigations carried out in the area of Gangi highlighting that the last tectonic phases are represented by prevalently kilometric NW-SE dextral strike-slip faults. In addition, near Mt Alburchia a set of normal NNW-SSE faults, related to the same system, cut red conglomerate and alluvial sands. Analytical observations on conglomerates display that some cobbles are offset by these faults. Taking into account the mechanical strength of cobbles it is likely that such ruptures represent a coseismic effect. Interestingly, some of these faults cut also Roman votive niches dated 4th century A.D.; one of them is offset about 14 cm. Historical and archaeological analyses show that this area was already settled in prehistoric time, and subsequently inhabited in Greek and Roman ages. At the Gangivecchio site, there is a prevalence of pottery pieces and coins dated from 1st to 4th century A.D., and an important decrease of the human activity is registered at the end of the 4th century. Furthermore, recent archaeological excavations have revealed a 4th century A.D. tomb where the remains of some women and children are found together. These common sepultures are unusual in the Roman culture. This behaviour and the important decrease of human activity can be seen as a consequence of an exceptional event, such as a natural disaster. Geological and archaeological evidence in the Gangi area are all suggestive of the occurrence of an event that produced important effects on the human and natural environment, possibly in the 4th century A.D. This event is conceivably a strong earthquake. Could it be the A.D. 361 earthquake located in Central Sicily by the historical catalogues?

### HISTORICAL EARTHQUAKE CATALOGUES AND ARCHAEOLOGICAL DATA: AVOIDING CIRCULAR REASONING – ID 1923

*T. Niemi, University of Missouri, United States*

An accurate earthquake catalogue is essential for assessing the seismic hazards of a region. Archaeological and geological data can both provide crucially needed data about both the date and intensity of ancient earthquakes. Earthquake data derived from archaeological excavations and geological studies should be viewed as a completely independent source of information from historical text. The archaeological record can constrain the date of past earthquakes by providing the age of fault rupture or of collapsed and seismically damaged features. The areal distribution of archaeologically-stratified, earthquake damage from several sites can be used to develop an isosesimal map, define the epicentral location, and possibly the magnitude of past earthquakes. However, the only way to avoid circular reasoning is if the earthquake damage at the archaeological site has been independently dated. The difficulty may not be in recognizing earthquake damage at archaeological sites but dating when it happened. Most structures have experienced more than one earthquake. Open vertical joints, horizontally shifted blocks, and other damage to extant structures can only provide a terminus post quem for an earthquake. Earthquake collapse horizons often fall onto living surfaces and occasionally have trapped victims, as is the case for the 363 A.D. earthquake at Petra and the 749 A.D. earthquake at Pella in Jordan. The date of the earthquake can be interpreted from the ceramic evidence, coins, and radiocarbon dating of organic material on the surface beneath the rubble. Sadly, the automatic association of collapse horizons to documented earthquakes in a catalogue has produced circular arguments that do not improve the study of ancient seismic events or produce any of the benefits described above. We must learn to carefully document the earthquake data from archaeological sites so that this information can be used to check and, if necessary, revise the established earthquake catalogues.

## SC-A 2: Volcano Seismology and Applications to Hazard Evaluation

Tuesday 17:15 - 18:30 – Room 7+8

### A MODEL FOR THE EVALUATION OF CUMULATIVE STRUCTURES DAMAGE IN THE VESUVIAN AREA UNDER SEISMIC ACTION – ID 1181

*G. Zuccaro, Centro Studi PLINIVS - Universtity of Naples, Italy*
*F. Cacace, Centro Studi PLINIVS - University of Naples, Italy*

The model represents the first attempt to assess the impact of a range of different volcanic hazards on the building structures in volcanic areas. This theoretical approach has been achieved within the activities of the Exploris project supported by the EU. The model considers three main hazard phenomena: earthquakes, ash fall and pyroclastic flows. Approaches to this work must take a hybrid form of stochastic and deterministic analyses, taking into account written histories of volcanic eruptions and expertise from field geologists to build up a semi-deterministic

model of the possible combinations of the above hazards that are situated both in time and space. A time history for SubPlinian I eruptive scenario is assumed by taking advantage from the expert elicitations and the following cumulative damage impact to the building structures due to a sequence of precursors seismic events is derived. This is achieved by new original definition of vulnerability functions for multi hazard input and a dynamic cumulative damage model. Factors affecting the variability of the final scenario are highlighted. The results show that some hazard combinations increase and others mitigate building vulnerability to subsequent eruptive phenomena

### SHEAR WAVE SPLITTING TIME VARIATION ON VOLCANIC AREAS: THE CASE OF MT. ETNA – ID 1669

*F. Bianco, INGV - Osservatorio Vesuviano, Italy*
*L. Zaccarelli, INGV - Osservatorio Vesuviano, Italy*
*L. Scarfì, INGV - Sez. Catania, Italy*
*E. Del Pezzo, INGV - Osservatorio Vesuviano, Italy*
*D. Patané, INGV - sez. Catania, Italy*

Shear-wave splitting is the elastic-equivalent of the well known phenomenon of optical birefringence. A shear wave propagating through an anisotropic solid splits into two S-waves that travel with different velocities and with different directions of polarization, generating two observables : TD that is the time delay between the two split S waves, and LSPD that is the polarization direction of the faster S wave. In the upper crust this phenomenon has been interpreted to occur in zones of fluid-filled cracks, microcracks or preferentially oriented pore spaces. The time evolution of anisotropic distribution of microcracks due to a differential stress, according to the nonlinear anisotropic poroelasticity (APE ) model, is explained by the fluid migration along pressure gradients between neighbouring microcracks and pores. In this framework the shear wave splitting parameters are indicators of the state of stress in the upper crust. We obtained shear wave splitting measurements for local earthquakes occurred before and after the last effusive eruptions at Etna volcano (Sicily, southern Italy) occurred in 2001, 2002 and 2004. All the dataset have been selected according to the shear wave window criteria. We observed time variation of TD in the band1, discussing also the possibility we were measuring spatial variation of anisotropy due to sources migration. LSPD is consistent with the direction of the compressive stress field acting in the area and show the 90-degrees flip for the different eruptions. We interpret the observed time changes of the splitting parameters as indicators of a complex stress changes, discussing their role as precursors of the eruptions in the investigated area.

### TWO INDICATORS OF THE VOLCANIC ACTIVITY FOR OPENED AND CLOSED SYSTEMS – ID 2061

*P. Palacios, Instituto Geofisico, Ecuador*
*H. Yepes, Instituto Geofisico, Ecuador*
*I. Molina, Instituto Geofisico, Ecuador*
*G. Cordoba, Universidad de Nariño, Colombia*

In order to characterize the pre–eruptive behaviour of the volcanic structure, considering it as a closed system, the time serial of the volcano – tectonic mean magnitude (VTMM) has been studied. Using the VTMM indicator has been possible to forecast the eruption of Galeras volcano on May 2004 and on November 2005. In the last case a prediction interval with 95% of probability was build. In addition, some rock experiments have shown general results that might explain the behaviour of the VTMM indicator in the pre–eruptive process. For opened systems an indicator that use the mean diary released energy (MDRE) has been proposed. The MDRE indicator takes into account the energy of tremors, explosions, long period, hybrid and volcano tectonic events. This indicator is a normalized and pondered measure that tries to integrate the physical variables. The MDRE indicator has been used to follow the eruption process of Tungurahua volcano and has an acceptable relation with the observed phenomenon. We believe that these indicators may be added to a real time procedure to construct early alerts.

### ANALYSIS OF CN SEISMICITY PATTERNS AT MT. VESUVIUS – ID 1952

*A. Peresan, University of Trieste, Italy*
*I. Rotwain, IIEPT. Russian Academy of Sciences, Russian Federation*
*I. Kuznetsov, IIEPT. Russian Academy of Sciences, Russian Federation*
*M. Rosso, University of Trieste, Italy*
*G. F. Panza, University of Trieste & ICTP, Italy*

The precursory seismic activation preceding moderate size earthquakes occurring at Mt. Vesuvius is investigated. In fact, though earthquakes in this area are not particularly strong (involving earthquakes with maximum magnitude Md= 3.6, since 1972), due to their shallow depths and to the high urbanization of the area, they can cause significant concern and damages. The possibility of intermediate-term prediction of moderate size earthquakes, with $M^3 3.0$, at Mt. Vesuvius is explored by making use of the formally defined algorithm CN, which is based on a set of premonitory seismicity patterns. CN, that was originally designed to identify the Times of Increased Probability (TIPs) for the occurrence of strong tectonic earthquakes, within a delimited region, is applied here to the analysis of earthquakes in volcanic areas. Satisfactory and stable prediction results are obtained, either by retrospective and forward analysis, when an appropriate time scaling is introduced. The predictive capability of the individual functions of the seismic flow, which are used to quantify the premonitory seismicity patterns in CN algorithm application, is analysed as well, in order to better understand the precursory activation characterising vesuvian micro-earthquakes. The outcomes of the performed experiments indicate that the formally defined premonitory patterns detected by the algorithm CN for strong tectonic earthquakes can be consistently observed in the seismicity at Mt. Vesuvius.

### THE METHODOLOGY OF QUANTIFICATION OF VOLCANIC EXPLOSIONS FROM BROADBAND SEISMIC SIGNALS AND ITS APPLICATION TO THE 2004-2005 EXPLOSIONS AT VOLCAN DE COLIMA, MEXICO – ID 1818

*V. Zobin, Observatorio Vulcanologico, Universidad de Colima, Mexico*
*C. Navarro, Observatorio Vulcanologico, Universidad de Colima, Mexico*
*G. Reyes, Observatorio Vulcanologico, Universidad de Colima, Mexico*

A methodology is proposed for the quantification of volcanic explosions based on three parameters derived from the broadband seismic signals: the counter force of the eruption F, the power of the explosion P, and the duration of the upward movement of the gas slug in the conduit to the magma free surface D. This methodology was applied to the 2004-2005 sequence of explosions at Volcán de Colima, México. The broadband records of more than 100 explosive events were obtained at a distance of 4 km from the crater. We determined the counter force of the eruption by modeling the low-frequency impulse of the seismic records of 66 volcanic explosions and estimated the power of 116 explosions from the spectra of the high-frequency impulse. The power of Colima explosions spans 5 orders of magnitude; the counter force spans 4 orders of magnitude. We show that the power of volcanic explosion is proportional to the counter force of the eruption. These parameters may be used for the elaboration of a scale of volcanic explosions.

## SC-B 1-I: Theory of Wave Propagation and New Techniques of Data Processing

Friday 10:45 - 12:15 – Room 15

### EXACT CAUSAL RELATIONSHIPS BETWEEN ATTENUATION AND PHASE VELOCITY IN LINEAR DISSIPATIVE MEDIA – ID 624

*K. C. Meza-Fajardo, ROSE School, Italy*
*C. Lai, EUCENTRE, Italy*

The theory of linear viscoelasticity has proved successful to describe, to a reasonable degree of accuracy, the cyclic behaviour of geomaterials at small strains under dynamic loading. Indeed it is the simplest constitutive model that can be adopted to predict the mechanical response of materials that have both the ability to store and dissipate strain energy. An important result that emerges from this theory is that phase velocity of body waves and material damping ratio (or equivalently the quality factor) are related by the Kramers-Kronig (KK) dispersion equations which are nothing else than a statement of the necessary and sufficient conditions for a material function to satisfy physical causality.

Explicit, simplified solutions of the KK relations have been long proposed in seismology and geotechnical earthquake engineering, however their applicability is limited by the various assumptions considered in their derivation (Aki and Richards, 2002; Meng, 2003). One of the most common of these assumptions is that material damping ratio in geomaterials is hysteretic in nature, namely is rate independent within the seismic frequency band. It is well know that several researches have questioned the validity of this hypothesis, but most importantly it is uncertain how the precise definition of the lower and upper bounds of seismic band will influence the frequency-dependence law of the phase velocity of body waves. This paper illustrates the derivation of closed-form solutions of the Kramers-Kronig relations to provide explicit, frequency-dependence laws for phase velocity and material damping ratio. The only assumption at the base of the derivation is rather weak and it is the so-called fading memory hypothesis which assumes that the current state of stress depends more strongly on the recent rather than on the distant strain history. The theoretical results have been validated using well-known solutions and experimental data for different types of geomaterials.

### IMPLEMENTATION OF A NON-SPLITTING FORMULATION OF PML IN A 3D 4TH-ORDER VELOCITY-STRESS FD SCHEME – ID 849

*A. Skarlatoudis, Aristotle University, Greece*
*J. Kristek, Comenius University, Slovakia (Slovak Republic)*
*P. Moczo, Comenius University, Slovakia (Slovak Republic)*
*C. Papazachos, Aristotle University, Greece*

One of the most usual and important problems in finite-difference methods is the truncation of the computational space by artificial boundaries, since such boundaries often produce spurious reflections, polluting the results with artificial noise. Among the various techniques, the Perfect Matching Layers (PML) approach seems to be the most efficient method for the implementation of artificial boundaries at the edges of the computational models. Wang & Tang (2003) presented a Non-Splitting formulation of PML (NPML) based on the introduction of small perturbations in the wavefield and applied their approach in the cylindrical coordinate system for calculating dipole and quadrupole waveforms in a logging-while-drilling environment. In this work the NPML technique in Cartesian coordinates and its implementation in a 3D 4th-order staggered-grid finite-difference scheme is elaborated. The accuracy and the efficiency of NPML in simple models of media are numerically examined. The results of this PML implementation were compared with the corresponding results calculated with the same finite-difference scheme but with the use of alternative non-reflecting boundaries. Moreover, different tests have been performed for examining the implication of the attenuating function and PML thickness relation in the overall PML performance. In general, PML performance is poorer, as expected, at grazing incidence angles but the power of spurious reflections is significantly lower in comparison with the alternative non-reflecting boundaries examined in this work. In general, large attenuating function coefficient values can produce strong reflections, whereas small values may lead to insufficient attenuation of the impinging waves. An alternative is to use a thicker PML zone, which significantly improves their performance at the cost of increased memory demand. The results show that in order to achieve an optimum memory usage while maintaining PML efficiency, the PML thickness and attenuating function coefficient values need to be specifically optimized for each examined simulation and model.

### MODELLING AND ASSESSMENT OF THE URBANIZATION EFFECT ON SEISMIC RESPONSE – ID 1023

*C. Boutin, ENTPE, France*
*P. Roussillon, BRGM, France*

Wirgin and Bard (1996) suggested that some specific features (beatings, long duration) of the seismic motion recorded in Mexico City during the 1985 Michoacan earthquake, could be explained by the energy re-radiated in their surroundings by the buildings involved in multiple soil-structure and structure-soil-structure interactions. The idea was supported by recent calculations based on various numerical descriptions. As a complementary approach, we present two analytical methods which aim at identifying the leading parameters of the site-city effect, and providing a better physical insight on the effect of the urban environment on the seismic response. The city is regarded as a periodic distribution of simple oscillators, whose period is small with respect to the wavelength in the soil. This simplifying, though acceptable assumption, allows a macroscopic description of the response of the city to a vertical SH wave. As a first approach, the effect of buildings is described by a mean impedance on the soil-city interface. This enables us to highlight a mechanical soil-city coupling parameter which governs the magnitude of the interaction, and to derive a characteristic time of the soil-city response. A second more refined model, is derived from a 2D homogenization method assuming the existence of a boundary layer at the soil-city interface in order to describe the near fields radiated by each building, and their multiple interactions. This provides an assessment of both free soil motion and building basement motion, separately. Applications are given for mono-frequency and multi-frequency cities, resting on homogeneous and stratified subsoils, under the incidence of vertical and oblique P or S plane waves. Effect of depolarisation and atypical mode conversions are also described.

### PROGRADE RAYLEIGH MOTION IN THE VALLEY OF MEXICO: THEORETICAL AND EXPERIMENTAL – ID 1746

*P. G. Malischewsky, Friedrich-Schiller-Universität, Germany*
*C. Lomnitz, UNAM, Mexico*
*F. Wuttke, Bauhaus-Universität, Germany*
*R. Saragoni, Universidad de Chile, Chile*

Theoretical results are derived for prograde ground particle motion in Rayleigh waves for a layer over a half-space, and relevant observations in the valley of Mexico are provided. we compute synthetic seismograms for a simplified model of the Texcoco site. In the earthquake of 19 September 1985 event we find prograde motion in Rayleigh waves within a specific frequency band. We show that the critical parameters for the existence of prograde waves are Poisson's ratio in the top layer and the shear-wave contrast between the layer and the half-space. For high values of these parameters the range of prograde motion lies approximately between the site frequency and twice the site frequency. The range of prograde motion depends also on Poisson's ratio and the impedance contrast between the layers. Particle motion research can provide useful constraints for the inversion of surface waves and for H/V studies.

### ARRAY ANALYSIS AND SOURCE LOCATION OF DEEP TREMOR IN CASCADIA SUBDUCTION ZONE – ID 1674

*M. La Rocca, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*D. Galluzzo, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*S. Malone, University of Washington, United States*
*W. McCausland, University of Washington, United States*
*G. Saccorotti, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*E. Del Pezzo, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*

Results of array and polarization analysis of deep tremor occurred in July 2004 in Puget Sound, Washington, recorded by three dense arrays, are presented. Many hours of tremor have been analyzed using the Zero Lag Cross-Correlation technique to estimate the propagation properties of the most correlated signals in the wavefield. Detailed polarization analysis has been computed using the covariance matrix method in time domain. Polarization parameters, joint with the results of array analysis, allows the discrimination between P and S coherent waves. Results show that the deep tremor wavefield is composed by body waves with a predominance of shear waves, although a consistent amount of signal is composed by coherent P waves. Backazimuth and slowness as function of time confirm that the source of deep tremor often migrates in a wide area. Many tremor sources have been located using a probabilistic method which can take into account both propagation values and travel times of the signals, at one ore more arrays, given a velocity model. The most of located tremors are characterized by depth in the range 30-40 km. Array and polarization analysis evidence many P-S wave pairs hidden in the almost stationary wavefield whose source is coincident within the location error with the tremor source. This result suggests the continuous occurrence of small, low stress drop, deep earthquakes as the most reasonable source of deep tremor. However, the spectra of deep tremor show a predominance of low frequency not observed in the spectra of small tectonic earthquakes recorded in the same area. Synthetic signals associated with double couple source mechanisms located in the same positions of the deep tremor source have been generated and compared with some P-S wave pairs observed in the deep tremor signal to infer on the source mechanisms of deep tremor.

### 3D MODELLING OF SITE EFFECTS IN TRICARICO (ITALY) – ID 1692

*S. M. Richwalski, CEDIM/GeoForschungsZentrum, Germany*
*I. Oprsal, Department of Geophysics, Charles University, Czech Republic*
*S. Parolai, GeoForschungsZentrum, Germany*
*M. Mucciarelli, DiSGG University of Basilicata, Italy*
*R. Wang, GeoForschungsZentrum, Germany*
*M. R. Gallipoli, DiSGG University of Basilicata/MAA-CNR Tito Scalo, Italy*

The town of Tricarico (Southern Italy) is situated on a calcarenite outcrop, which is underlain by argillaceous material with lower shear wave velocity, a common situation for many towns in this region (e.g. DiGiacomo et al, BSSA, 2005). Therefore, local 3D site effects due to the topographic sedimentary cover and the geometry of the sub-surface may reasonably contribute to possible damages in the urban area in case of an earthquake. The respective earthquake hazard is moderate to high according to the Italian official seismic classification (0.25 g for a return period of 475 years). Damage was reported during the 1694, 1857, and 1980 earthquakes. Microtremor measurements and accelerometric monitoring of earthquakes were conducted in the town and the analysis of the data showed several features related to site effects: the level of spectral amplification depends on wave type and the spectral amplification level differs between the two horizontal components. From geological and geo-engineering information, we constructed a detailed 3D model of the sub-surface underneath the town and included surface topography. The 3D finite-difference modelling of the site effects features a reasonable spectral amplification due to topography. It has a maximum at frequencies between 1.5 and 5 Hz, where it may exceed 5. A dependency on the azimuth of the incoming wavefield is apparent. Amplification due to basin-like structures starts to dominate the spectral acceleration at frequencies higher than 3 Hz and seems to be less dependent on the azimuth of the incoming wavefield.

## SC-B 1-II: Theory of Wave Propagation and New Techniques of Data Processing

Friday 13:30 - 15:00 – Room 15

### GROUND MOTION SCALING IN ISRAEL – ID 1849

*T. Meirova, Tel-Aviv University, Israel*
*R. Hofstetter, Geophysical Institute of Israel, Israel*
*Z. Ben-Avraham, Tel-Aviv University, Israel*
*L. Malagnini, Nazionale di Geofisica e Vulcanologia, Italy*

A regional study of earthquake ground motion scaling relationships is essential for the design of requirements for the construction of earthquake resistant structures and facilities. The main goals of our work are to overcome the restrictions of Boore (1994) ground-motion relation, and understand the effects of the seismic source, propagation in the Earth's crust and local site conditions in Israel and adjacent areas. For this purpose we use the regression technique that was proposed by Yazd (1993), Herrmann (1999), Raoof et al. (1999) and Malagnini et al. (1999). The undoubted advantage of this method is the possibility to use for analysis data from frequent, small earthquakes that are typical for this region. For the analysis we used 4814 waveforms recorded by 32 Israel Seismic Network stations since 2000 to 2005. Under the condition that the records are obtained at more than 5 observations, we select 330 appropriate earthquakes, with a magnitude range between 1.8 and 5.2. We derived the empirical excitation, site, and attenuation by the regressing peaks amplitudes of shear-waves measured from the bandpass filtered waveforms. Theoretical modeling was performed by Random Vibration Theory on the parameters derived from observations. For prediction we used the quality parameter Q(f) = 205*f∧0.7 and trilinear geometrical spreading g(r) r∧-5/6 for r < 60 km, r∧0 for 60 km < r < 70 km, r∧-0.4 for r > 70 km. Modeling of the excitation terms was based on the Brune's source spectrum. Analysis of regional attenuation function was performed for three different tectonic provinces. It was found that the rate of decaying of shear waves is more rapid in Northern Israel than in Central Israel, whereas southern part of Israel has no prominent difference with Central Israel.

### UNDERSTANDING THE EFFECTS OF WRONG SENSITIVITY KERNELS IN TOMOGRAPHIC INVERSION THROUGH THE NEW DISTORTION-SPECTRUM APPROACH – ID 1892

*B. H. Jacobsen, Dept. Earth Sciences, Denmark*

In several important linear and linearized problems the inverse operator is derived from a linear forward mapping which is deliberately approximated for simplicity or for computational efficiency. An important example is seismic traveltime tomography based on ray curve integrals of slowness anomaly, yet the actual traveltime sensitivity is distributed in a more or less tube like shape along the mathematical ray.

A deeper understanding of this problem is possible through analysis of the "distortion spectrum", which is computed by singular value decomposition of a matrix expression derived from a combination of both the (near) exact forward mapping and the employed approximate mapping as well as optional covariance matrices of noise and model variations.

This presentation demontrates that the effect of the ray approximation on the inverse estimates in seismic tomography may range from harmless perturbations to more adverse distortions

of the model estimates depending not only on the measurement geometry and the average sound velocity distribution (i.e. the ray distribution), but also on the character of the velocity anomalies.

### AUTOMATIC PHASE PICKING METHODS FOR HIGH-END SEISMOLOGICAL APPLICATIONS – ID 2006

*F. Aldersons, scientific consultant, Switzerland*

Advanced seismological applications usually require high-quality seismic phase arrival times. Which single-trace methods, applicable on a wide range of data, can be used to automate the determination of arrival times for high-end applications ?

First of all, high but realistic quality requirements need to be defined and met throughout the picking process. As a consequence, only quite adequate components can be connected together in what we call a complete picking 'system'.

Among frequency filters that can be used to increase the signal-to-noise ratio of seismograms, it is possible to design optimal zero-phase F.I.R. Wiener filters that do not distort the true shape of onsets. We further show that Wiener filters implemented in the frequency domain can derive Power Spectra from short data segments by using the Maximum Entropy Method.

It is still unclear, on a wide range of data, which picking algorithms perform best. For P-waves, we have found interesting synergies to exist between the Baer-Kradolfer (1987) and the Takanami-Kitagawa (1988) picking algorithms.

Successful single-trace automatic picking usually results in the vast majority of automatic picks to be at least reasonably accurate, and the presence of some outliers. Since barely a few percent of outliers can jeopardize the meaning of high-end applications, reliable automatic picking systems need, at the very least, to be able to detect and down-weight their less reliable picks.

We have designed an automatic picking uncertainty assessment method. The method attempts to determine the true uncertainty class (±50ms, ±100ms, ...) for every reported arrival time. The task is made possible, after calibration, from the discriminating power provided by up to 9 predicting variables measured on every seismogram. The calibration involves Reference picks and uncertainties defined by the user, followed by a Discriminant Analysis (Fischer, 1936) performed in a multi-variate statistical package.

### JOINT INVERSION OF SEISMIC REFLECTION TRAVELTIMES AND WAVE POLARIZATIONS – ID 1821

*J. Chen, Institute of Geophysics, China*
*J. Badal, University of Zaragoza, Spain*
*J. Teng, Institute of Geophysics, China*

In the context of wide-angle seismic profiling, the determination of the physical properties of the Earth crust, such as the elastic layer depth and seismic velocity, is often performed by inversion of P- and/or S-phases propagation data either fixing the geometry of the medium (reflector depths) or any other structural parameter (P- or S-wave velocity, density). Moreover, the inversion for velocity structure and interfaces is commonly performed using only seismic reflection traveltimes and/or crustal phase amplitudes in isotropic media. In an attempt to restrict the non-uniqueness of the solution, we present a simultaneous inversion method of seismic reflection traveltimes and polarizations data of transient elastic waves in stratified media to reconstruct not only layer depth and vertical P-wave velocity, but also the anisotropy character of the crust based on the estimation of the Thomsen parameters. We first carry out a checking with synthetic data comparing the outputs obtained by simulated annealing and joint inversion of seismic reflection traveltimes and polarizations data. This comparison proves that whereas the results obtained by annealing deviate appreciably from the expected ones, those obtained by the nonlinear inversion approach fit nearly the starting model. Then, we investigate the geometry, P-wave velocity structure and anisotropy of the crust beneath Southeastern China by applying the proposed inversion method to previously acquired wide-angle seismic data. In this case the anisotropy signature provides clear evidence that the Jiangshan-Shaoxing fault is the natural boundary between the Yangtze and Cathaysia blocks.

### CYTHERA M6.7 EARTHQUAKE (JANUARY 8, 2006) IN SOUTHERN AEGEAN: UNEASY RECOGNITION OF THE UPWARD RUPTURE PROPAGATION – ID 1859

*J. Zahradnik, Charles University, Czech Republic*
*J. Jansky, Charles University, Czech Republic*
*V. Plicka, Charles University, Czech Republic*
*E. Sokos, University of Patras, Greece*

This earthquake is important because: (i) last event of comparable magnitude occurred in the region 100 yr ago, (ii) in long-term sense the event was predicted by Papazachos et al. (2002), (iii) nodal planes are not parallel to the main structure, the Hellenic arc, (iv) it is an intermediate-depth event, maybe the best recorded so far in the region, thus providing opportunity to study such events representing a significant threat in southern Aegean, including possible tsunami. This contribution is based on phase data and broad-band waveforms accessible from international centers through Internet: 30 teleseismic and 9 regional 3-component records. The earthquake did not allow a simple processing. Instead, a non-standard combination of various data sets was needed. Focal depth was best constrained by teleseismic records using pP-P (and a few sP-P) times, and by waveform fitting. Using the resulting depth (80-90 km) as a first approximation for the regional location (21 stations in Greece and Italy), the epicenter was found at about 15 km south and 5 km east of the EMSC determination. The location included optimization of the Vp/Vs ratio (= 1.75) through Wadati diagram and RMS minimization, as well as a play with several data subsets and weights. Teleseismic waveforms suggested 2 to 3 subevents of a slightly different focal mechanism. Using the same crustal model as that in the hypocenter (H) location, regional waveforms were inverted into the centroid moment tensor. The centroid position (C) was found at about 20 km eastward from H, and 20 km upward. Mutual position of H, C and the nodal planes was used to identify the fault plane, independently confirmed by forward wavefield simulation of a simple finite-extent source model. Fault complexity (two slip patches) was also indicated by non-linear inversion of the apparent source time functions from empirical Green's functions.

### SEISMIC AND INFRASONIC OBSERVATIONS IN NORTHERN FENNOSCANDIA – ID 1843

*J. Schweitzer, NORSAR, Norway*
*F. Ringdal, NORSAR, Norway*
*T. Kværna, NORSAR, Norway*

Since some years the small aperture seismic array in Apatity has been additionally equipped with three infrasound sensors. The infrasound signals observed with these sensors are regularly transmitted together with the seismic data and can now be jointly analyzed. The Apatity array is about 370 km apart from the small aperture seismic array ARCES.

Because of special construction conditions of the individual sites of ARCES, most of its seismic sensors are also sensitive to stronger infrasound signals. In the fall of 2006, NORSAR plan to build a CTBT infrasound array near ARCES.

In preparation for the new infrasound array, infrasound signals from Apatity and from ARCES were investigated.

Comparing the infrasound signals with know seismic sources it is obvious that many infrasound signals are coming from explosions in known open pit mines or from military camps where larger amounts of ammunition are destroyed.

Infrasound signals from any given event show a high correlation across the observing arrays. However, when comparing recordings of different events from the same source region and recorded at the same station, there is a large variability in infrasonic signal waveforms, whereas the seismic signals are very similar.

## SC-B 2-I: The 20th Century Strong Euro-Mediterranean Earthquakes from Historical Seismograms

Monday 13:30 - 15:00 – Room 18

### EUROSEISMOS PROJECT 2002-2006: OBJECTIVES AND MAIN RESULTS – ID 2013

*G. Ferrari, SGA Storia Geofisica Ambiente srl, Italy*

The study of the great earthquakes and the analysis of their tectonic significance are very important elements in the evaluation of seismic potential, seismic hazard and risk. The analysis of the seismograms of historical earthquakes plays a crucial role in understanding the patterns of deformation energy release, the characteristics of propagation and interaction of the seismic waves with the inhabited areas, in the areas affected by these events. The recovery and reproduction of historical seismograms and the indispensable information contained therein, on the instruments that recorded them and their related characteristics, often become difficult and laborious operations that deprive research of a disproportionate amount of human and economic resources in relation to the objective complexity of the matter. These difficulties have so far much reduced the number of study cases and have been a disincentive to researchers interested in dealing with this important research strand. In order to overcome these difficulties the EuroSeismos Project has been started up (http://storing.ingv.it/Es_web) this is a project for collaboration between researchers and research bodies having a long tradition of seismic monitoring, with the following main objectives: 1) the recovery, with the reproduction at the SISMOS centre of the INGV in Rome (http://sismos.ingv.it), of the seismograms of the most important historical earthquakes (1895 – 1980) in the Euro-Mediterranean area in the 20th century; 2) benchmarking of experiences on the processing of seismographic historical data; 3) creation of a permanent workgroup on these aspects. So far 33 researchers belonging to 29 Euro-Mediterranean countries have joined the project. The approximately 300 earthquakes of primary interest for the researchers involved have been collected in a catalogue. Until now about 25,000 seismograms of 114 Euro-Mediterranean seismic stations have been scanned and the reproduction of the seismograms of 4 more station are planned for the end of 2006.

### THE SISMOS FACILITY AT INGV – ID 1957

*A. Michelini, INGV, Italy*
*T. Sismos, INGV, Italy*

We describe the current status of the SISMOS activities at INGV. SISMOS is the largest historical seismology preservation facility existing worldwide. At the origin of this facility is the "Progetto SISMOS" that started in the late ‘90s and it was aimed primarily toward the preservation of the then mainly on paper Italian seismological patrimony archived by the different observatories exiting in Italy since the late 1800. This patrimony includes mainly historical seismograms and bulletins subject to progressive deterioration and inevitable loss. In 2002, the SISMOS activity was extended to seismograms and bulletins from observatories in 28 countries of the Euro-Mediterranean area through the European Seismological Commission Working Group on the History and Data of Instrumental Seismology, the EuroSeismos project (http://storing.ingv.it/es_web/). The main products of SISMOS available through the Web server (http://sismos.ingv.it) include: digital images of paper record seismograms, digital images of historical seismic bulletins, and software for the analysis of the digital image seismograms. Future products will include: digital vector data of selected seismograms and alphanumeric data of historical bulletins. It is expected that easy access to collections of these seismic records will prompt modern reappraisals of historical earthquakes and lead to revaluations of seismic hazard. The current database includes more than 100,000 seismic records ( 20,000 from the EuroSeismos project) and a few hundreds bulletins all available at the SISMOS web site (http://sismos.ingv.it). For seismogram vectorization, SISMOS has developed the software Teseo2 (Pintore et al., CAGEO 31, 1277-1285, 2005) that, in its most recent version, allows for digitization of record digital images to provide ready-to-use seismogram in SAC format after all the required corrections are applied. Current developments aim toward enlargement of the database through the recently funded NERIES project and the analysis of the most important historical earthquakes that have occurred in the EuroMed area.

### STORING AND DISSEMINATING THE INFORMATION AND DATA OF HISTORICAL INSTRUMENTAL SEISMOLOGY: THE TROMOS DATABASE AND THE EUROSEISMOS WEBSITE – ID 2036

*G. Tarabusi, SGA - Storia Geofisica Ambiente, Italy*
*G. Ferrari, SGA - Storia Geofisica Ambiente, Italy*
*M. Caciagli, SGA - Storia Geofisica Ambiente, Italy*

Within the scope of TROMOS 1990-2006 (INGV-SGA) and EuroSeismos 2002-2006 (http://storing.ingv.it/Es_web) projects, coordinated and partly set up by SGA within the Italian and the European spheres, a vast quantity of important data have been made available for the study of the major earthquakes of Euro-Mediterranean area. In this regard, since 1990, the TROMOS database was set up and regularly updated. Since November 2002 the project web site has been operative, entirely updated automatically by the TROMOS database by means of complex procedures of generation. The web site of EuroSeismos has a dual function: informing on the state of progress of the project and allowing a rapid consultation of the data collected for each earthquakes affected by the project. The automatic updating procedures, starting from the exporting of the TROMOS database as well as that of SISMOS (http://sismos.ingv.it), allow for the regeneration in a short time of the over 4,000 pages of the site through which it is possible to search for a single event, both on chronological and geographical grounds. By selecting a single earthquake, it is possible to access a dynamic map of the observatories for which seismogram scans are available and to see directly a preview by means of a direct link to the files present in the Sismos database. The same geographical data are today available also in the Google Earth© format. Also reported, where available, is the main information relating to the observatories and the characteristics of the recording instruments. The project also fosters the recovery and the digital scanning of the complementary documentation represented by station bulletins and handbook. So today we have at our disposal the consultation and download of 1.045 different PDF files of bulletins from many Euro-Mediterranean stations reproduced within the framework of Euroseismos and made available by the Partners.

### HSDB HISTORICAL SEISMOMETRY DATABASE PROJECT – ID 1543

*A. Bono, INGV, Italy*

Sismos is the italian team in charge of the digital archive of paper record seismograms and of historical seismic bulletins since the last years of 19th century. The Working Group History and Documents of Instrumental Seismology, as a part of ESC, promoted an EuroSeismos Project in order to spread Sismos venture in all European partners. This took such group to become the leading firm in the recovering and reprocessing of historical seismological data. As of February 2006, more than 93,000 seismogram records have been scanned and made available. The database architecture we propose here is the result of this experience: it's the upcoming new database schema for Sismos archive. We consider it useful for those who are approaching to "recovery and reprocess" computer based facilities. Schema description will be divided into two portions. We will show a parametric schema regarding seismic stations, instruments, sismic events, hypocentral locations and parameters. In a second part, we will show tables regarding seismograms, bulletins and other records. A whole picture of the

schema will be provided too. We will point out that a wide variety of data manipulation operations are possible. For example, users can set up different "versions" of the same earthquake, linking them with potentially different phase arrivals and seismograms. This allows independent researchers to examine an event with virtually no restrictions on customization. Besides, it's possible to trace seismometers' configuration parameters and location during their whole lifetime. In fact, Seismic Instruments are classified in a mixed gerarchical-relational way going down from prototype to parameters. Each record in the parameters table represents changes in the configuration. Sismos engineers designed a registered user web portal to the SISMOS archive and some interesting features are availbe at http://sismos.ingv.it. Database creation scripts for Oracle and MySQL are also available on request.

### MOMENT MAGNITUDE ESTIMATION OF GREAT LATE 19TH AND EARLY 20TH CENTURIES EARTHQUAKES FROM THE OLD SEISMOGRAMS OF GEODYNAMIC OBSERVATORIES IN THE ISCHIA ISLAND (SOUTHERN ITALY) – ID 1981

*J. Batlló, Observatori de l'Ebre. CSIC - URL, Spain*
*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*
*R. Macià, Dept. Matemàtica Aplicada II, UPC, Spain*

Designed by Giulio Grablovitz (1846 – 1928) in 1885 on behalf of the Ministry of Agriculture, the Royal Geodynamic Observatory of Casamicciola and Porto d'Ischia started its activity in 1891. Over several decades at the observatories of Ischia, Grablovitz designed, developed and implemented numerous instruments, some of which even crossed the national borders to be installed in a number of foreign observatories. The seismological activity was officially suppressed in the early 1920s, although the recordings continued to the 1930's . Forgotten for several decades, the historical materials had remained stowed away in the rooms of the observatory, while the dampness and partial decay of the rooms has to some extent damaged part of the documentation. In 2001, SGA, within the scope of the TROMOS project of the National Institute of Geophysics and Volcanology (INGV), recovered these precious historical materials and submitted them to a process of restoration, digital reproduction, cataloguing and study. The material, which is still being reorganised, includes, at least, 2000 letters (sent and received), photographic plates of instruments and recordings (not few than 10000 seismic recordings from 1895 to the late 1930s). The seismograms have been the subject of painstaking conservative restoration, undertaken by experts in the field, and digital scanning within the scope of the SISMOS project of the INGV. The most useful seismograms of several strong earthquakes occurred in the world in the period 1895 – 1905, with particular attention to the recordings of the Grablovitz seismic tank and horizontal pendula, have been digitized and moment magnitude for these earthquakes calculated. Between these earthquakes we remember the Assam (Southern India) of June 12, 1897 (M= 8.0) and the Istanbul (Turkey) of May 20, 1899 (M= 6.5) ones. Here we present the results obtained concerning the historical and cultural recovery, as well as the scientific use of the data.

### THE CHAMONIX, 1905, EARTHQUAKE: FOCAL MECHANISM DETERMINATION BASED ON TWO GOETTINGEN WIECHERT RECORDS – ID 1866

*M. Cara, EOST-IPGS, France*
*P. J. Alasset, GSC, Canada*
*L. Rivera, EOST-IPGS, France*
*J. Van Der Woerd, EOST-IPGS, France*
*J. Frechet, EOST-IPGS, France*

A moderate size Mm 5.5 - 6 earthquake occurred next to the French-Swiss border, on April 29, 1905. We use historical records in combination with macroseismic and tectonic observations to help constrain both the seismic moment and the focal mechanism of this earthquake at the early age of instrumental seismology. In order to benefit from the robustness of surface-wave modelling at low frequency, a good signal-to-noise ratio is required at periods larger than 20s. The only records we have found fulfilling these requirements come from the Wiechert inverted pendulum of Göttingen. The 1905 earthquake occurred in an area where several identified faults are visible in the crystalline outcrop of the Mont-Blanc and Aiguilles Rouge massifs (e.g., Leloup et al., 2005). We have tested several focal mechanisms and focal depths in the range of 3-10 km to check the low frequency part of these 1905 Göttingen records: 1) a N20E left-lateral normal fault, the Remuaz fault, investigated by Alasset (2005); 2) the N60E right-lateral strike-slip fault of the ML= 4.9 Vallorcine earthquake which occurred in the vicinity on September 8, 2005; and 3) two thrust faults parallel to the main thrust zone (N50E) of the Mont-Blanc massif. Using the computer codes of Hermann (2002) and a simple crustal model adapted to the epicentre-station path, we have computed the NS and EW synthetic Wiechert seismograms. The synthetics corresponding to the right-lateral strike-slip fault mechanism of the recent Vallorcine event do not fit the Göttingen records, while those corresponding to the focal mechanism associated with the left-lateral normal Remuaz fault fits the observed records reasonably well. Using the Remuaz fault focal mechanism, we find a seismic moment of M w = 5.5 for the 1905 earthquake. Additional models and tests currently in progress to better constrain the depth and possible mechanisms of the 1905 event will be discussed.

## SC-B 2-II: The 20th Century Strong Euro-Mediterranean Earthquakes from Historical Seismograms

Monday 15:30 - 17:00 – Room 18

### 1911 SWABIAN JURA, SOUTHERN GERMANY EARTHQUAKE: A REAPPRAISAL USING SEISMOGRAMS – ID 2021

*D. Kaiser, Federal Institute for Geosciences and Natural Reso, Germany*
*J. Batlló, Observatori de L'Ebre, Spain*
*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*
*R. Macià, Dept. Matemàtica Aplicada II, UPC, Spain*

With the earthquake of 16 November 1911, one of the largest earthquakes in Central Europe, significant seismic activity started in Swabian Jura (Southern Germany) and continued with several damaging earthquakes throughout the 20th century. No major earthquake is known before this event in this region that is now considered to be one of the most active in Central Europe. All earthquakes occur in a small region of 10 km extent in the upper crust and show very similar strike-slip focal mechanisms that can be related to a N-S striking shear zone of sinistral type with no obvious surface expression. Since the seismogram interpretation by Gutenberg (1915) and the macroseismic analysis by Sieberg & Lais (1925) no in-depth studies of this earthquake are available. This event is amongst those considered to have a high priority in the list of earthquakes included in the EuroSeismos project (http://storing.ingv.it/es_web). In the database of the SISMOS project – INGV (http://sismos.ingv.it), which also collects the digital scans of the seismograms recovered for each event of the EuroSeismos project, 35 recordings from 16 different Euro-Mediterranean observatories are available for this earthquake. Useful records have been digitised with the Teseo software tool and the resulting vectorization signal has been the subject of appropriate corrections on the basis of the instrumental constants of the historical seismographs. Hence, it was possible to obtain a re-evaluation of the main seismological parameters of the event. A comparison between these parameters and those from previous studies are discussed.

### THE ALTA VAL TIBERINA (ITALY) EARTHQUAKE OF 26TH APRIL 1917: REASSESSMENT OF THE MAIN SEISMOLOGICAL PARAMETERS. – ID 1987

*M. Caciagli, SGA - Storia Geofisica Ambiente, Italy*

*B. Palombo, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*J. Batlló, Observatori de l'Ebre., Spain*

The event on 26th April 1917 at 9:35:59 hours (GMT) located in the Alta Val Tiberina (Italy), is part of a series of strong earthquakes that, in the four-year period 1916-1920, affected an area of the Apennines from the Adriatic coast to North Tuscany included within the regions of Romagna, Tuscany and Umbria, and that have been the subject of numerous recent macroseismic studies. The Catalogue of Strong Italian Earthquakes (http://storing.ingv.it/cft/), classifies 134 locations in regard to this earthquake, which particularly struck some centres situated on hillside reliefs to the right of the flow of the River Tiber (Monterchi, Petretolo and others) and had a maximum and epicentral intensity equal to the IX-X degree of the MCS scale, with magnitude equivalent to 6. This event is amongst those considered to have a high priority in the list of earthquakes included in the EuroSeismos project (http://storing.ingv.it/es_web). In the database of the SISMOS Project – INGV (http://sismos.ingv.it), which also collects the digital scans of the seismograms recovered for each event of the EuroSeismos project, 41 recordings from 16 different Euro-Mediterranean observatories are available today for this earthquake. After the vectorialization of the seismograms, performed using Teseo software (http://sismos.ingv.it/teseo/), the correction of the signals on the basis of the instrumental constants of the historical seismographs was performed. Hence, it has been possible to obtain a reassessment of the main seismological parameters of the event and the comparison between these parameters and the same ones extrapolated from macroseismic data is discussed.

### THE SANTA SOFIA (ITALY) EARTHQUAKE ON 10TH NOVEMBER 1918: SEISMOLOGICAL PARAMETERS FROM HISTORICAL SEISMOGRAMS. – ID 2002

*G. Tarabusi, SGA Storia Geofisica Ambiente, Italy*
*B. Palombo, INGV - Centro Nazionale Terremoti, Italy*
*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*

On 10th November 1918 at 15:12:28 (GMT) an earthquake hit the Apennines surrounding Forlì (Italy). This was part of a series of five strong earthquakes that, in the four-year period 1916-1920 struck the Northern Apennines from the South-East (Adriatic coast, May 18 and August 15, 1916) to North-West (Garfagnana, September 7, 1920). According to the Catalogue of Strong Italian Earthquakes (http://storing.ingv.it/cft/), which has 188 felt reports for this event, it had a maximum and epicentral intensity of the IX degree of the MCS scale, with equivalent magnitude 5.9 and a macroseismic epicentre of coordinates: 43.42 N and 11.93 E. The worst hit villages were Mortano, San Piero in Bagno, Santa Sofia and other locations situated within a range of about a dozen kilometres. The EuroSeismos project (http://storing.ingv.it/es_web) considers this event to be one of those having a high priority in the list of earthquakes. The project seeks seismic recordings that come from the observatories of the various Euro-Mediterranean partners. In the database of the SISMOS Project – INGV (http://sismos.ingv.it), which also collects the digital scans of these seismograms, 33 recordings from 13 different observatories are currently available for this earthquake. In order to obtain the first tentative evaluation of the most important parameters of the event, with the help of the Teseo software (http://sismos.ingv.it/teseo/) a vectorialization of the available recordings was performed. The necessary corrections were made to the signals by means of the search for the related instrumental constants of the different historical seismographs. The comparison between these parameters and the ones calculated from macroseismic data is discussed here.

### THE MUGELLO (ITALY) EARTHQUAKE OF THE 29TH JUNE 1919: RE-EVALUATION OF THE SEISMIC PARAMETERS FROM HISTORIC SEISMOGRAMS – ID 2012

*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*
*G. Tarabusi, SGA Storia Geofisica Ambiente, Italy*
*B. Palombo, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

The strong earthquake that hit the Mugello (Tuscany, Italy) on 29th June of 1919 at 15:06:13 (GMT) has been the subject of recent macroseismic studies. This earthquake is part of a series of five strong earthquakes that, in the four-year period ranging from 1916-1920, struck the Northern Apennine from South-East (Adriatic coast, May 18 and August 15, 1916) to North-West (Garfagnana, September 7, 1920). The parameters drawn from the Catalogue of Strong Italian Earthquakes (http://storing.ingv.it/cft/), which has 568 felt reports for this event, indicate a maximum epicentral intensity equal to the X degree of the MCS scale, with equivalent magnitude equal to 6.3 and a macroseismic epicentre of coordinates 43.95 N and 11.48 E. The worst hit centres underwent extensive destruction and numerous rural houses collapsed completely. Serious damage also occurred in the upper Casentino, in the Valdarno area and in the Apennine villages of the Romagna region, where the shock increased the damage of the areas already hit by the earthquake on 10th November 1918. This event is present in the list of high-priority earthquakes of the Euroseismos project (http://storing.ingv.it/es_web). The database of the SISMOS Project – INGV (http://sismos.ingv.it), which also collects the digital scans of the seismograms recovered during the EuroSeismos project, comprises 33 recordings from 16 different Euro-Mediterranean observatories. After the vectorialization of the useful seismograms effected using the Teseo software (http://sismos.ingv.it/teseo/), through the retrieval of information relating to the instrumental constants of the various historical seismographs, the necessary corrections to the signal were performed, and it has been possible to obtain a re-evaluation of the most important parameters of the event. The comparison between these parameters and the same ones calculated from macroseismic data is discussed here.

### THE EARTHQUAKE IN NORTHERN MARCHE (ITALY) ON 30TH OCTOBER 1930: REASSESSMENT OF THE SEISMIC PARAMETERS FROM HISTORICAL SEISMOGRAMS – ID 1998

*M. Caciagli, SGA - Storia Geofisica Ambiente, Italy*
*A. Nardi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*J. Batlló, Observatori de l'Ebre., Spain*

The earthquake of the 30th October 1930 at the 07:13:06 (GMT) that hit the central-northern coastline area of the Marche region was felt all across central-northern Italy, as far as north as Istria, and as far as Naples and Apulia. In the Catalogue of Strong Italian Earthquakes (http://storing.ingv.it/cft/), this earthquake has an epicentral intensity equal to the VIII degree of the MCS scale, an equivalent magnitude of 5.9, both calculated from 250 felt reports. The earthquake's maximum effects were in Senigallia, where 318 houses collapsed and 2,000 were seriously damaged. Total collapses and numerous unstable houses were reported at Montemarciano, Mondolfo, San Costanzo, Fano, in some quarters (Capodimonte and San Lazzaro) and in the neighbourhoods of Ancona. About 40 more locations suffered damage of certain importance. No recent studies performed from seismograms are available for this earthquake. This event is in the high priority list of earthquakes of the EuroSeismos project (http://storing.ingv.it/es_web). For the earthquake being studied today we have 64 recordings available from 22 different Euro-Mediterranean seismological observatories or stations. Many of these records have been recovered within the framework of the Euroseismos project and are stored in digital format in the SISMOS Project – INGV (http://sismos.ingv.it) database. After the vectorialization of the seismograms, performed using Teseo software (http://sismos.ingv.it/teseo/) and the correction of the signals on the basis of the instruments constants of the historical seismographs it has been possible to achieve a tentative revaluation of the event's main seismological parameters. The results of these studies are presented here.

### CONTRIBUTION TO THE STUDY OF THE 1951 EARTHQUAKES IN SOUTHERN SPAIN – ID 1846

*J. Batlló, Observatori de l'Ebre, CSIC-URL, Spain*
*D. Stich, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*B. Palombo, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*R. Macià, Dept. Matemàtica Aplicada II, UPC, Spain*
*J. Morales, Instituto Andaluz de Geofísica, Spain*

In 1951, a long series of more than 90 reported earthquakes, lasting from March to September, struck the region of Jaen in Southern Spain (3.0°-4.5° W, 37.5°-38.5° N). This included two magnitude 5+ shocks on March 10th and May 19th. Since the first studies of the earthquakes, many contradicting estimates for location and depth of these earthquakes have been published, and no consensus has been reached. Especially, it has been proposed that one or both of the main earthquakes had an intermediate deep focus, which would imply fundamental rethinking of the established regional tectonic framework.

The EUROSEISMOS project allowed collecting many seismograms and bulletins for these earthquakes. The new collection of seismograms and recorded phases allow us to search for a more precise epicentre location and scalar moment determination. Based on the bulletin data, a relocation using Lomax algorithm is done for as many as possible earthquakes of the series. Based on digitized waveform data from 10 regional recording stations, we characterize the source process of the two main events using deconvolution of aftershock waveforms and moment tensor inversion.

Comparison of seismograms from the two main events reveals striking similarity, pointing to a doublet character of these earthquakes, with nearby locations and similar source mechanisms, and contradicting a significant event dispersion as observed previously. From a technical point of view, the recording of the 1951 Jaen doublet at a network of common stations offers an excellent possibility to validate the performance of classic mechanical recording systems, as well as the precision of our processing sequence based on manual digitizing. It consequently allows to stabilize source retrieval for the main events by limiting the analysis to the coherent portion of waveforms, which is reproduced with basic similarity in redundant seismograms.

## SC-C 1-I: Earthquake Source Complexity: From Geology Through Kinematic and Dynamic Models to Realistic Ground Motion Simulations

Thursday 10:45 - 12:15 – Room 18

### PATTERN OF LONG TERM BEHAVIOR OF NORTH TEHRAN FAULT- A PALAEOSEISMOLOGICAL APPROACH – ID 890

*A. Naderzadeh, Maharem Group, Iran (Islamic Republic Of)*
*R. Madani, Mahab Ghods Consulting Company, Iran (Islamic Republic Of)*

North Tehran fault (NTF) with a dominant compression mechanism and an E-W trend forms the northern boundary of Tehran megacity plain. In western parts, the NTF has softly displaced the gullies with a low rate. Due to the lack of shutter ridge in alluvial fans and the absence of sudden offset along NTF, the brittle deformation condition is not dominant. In earthquake catalogues, no seismic event is definitely attributed to NTF, and important earthquake events have been related to the Mosha, South and North Ray faults. Imamzadeh Davood Fault (IDF) with a NW-SE trend and an obvious displacement in ridges reaches to NTF through its southeast termination. Through this region many slickenside systems can be observed along NTF as an index of brittle deformation condition. A site was selected near the junction of NTF and IDF to investigate palaeoseismology. For this purpose, three vertical trenches were excavated. Three colluvial–alluvial sequences could be logged on the trench walls, each one consisted of an immature-angular colluvial horizon at base and sorted-rounded alluvial horizon at top. It is supposed that the colluvial and alluvial deposits correlate with seismic events and Inter-seismic phase, respectively. Two samples were taken from upper part of each inter-seismic horizon for dating by thermo-luminescence dating method, and a 6700±250y return period was finally obtained for an event with characteristic magnitude. Considering above and assuming a 0.3 mm/year average constant slip rate for NTF, a maximum magnitude 6.7-6.8 can be expected due to NTF future probable movement. The latest seismic event along NTF dates back to 6800±525 years ago unless the earthquake of 958 AD is attributed to this fault.

### EARTHQUAKE SOURCE COMPLEXITY IN THE MARMARA SEA AND ITS INFLUENCE ON GROUND MOTION SIMULATIONS – ID 1318

*K. Atakan, Department of Earth Science, University of Bergen, Norway*
*M. B. Sørensen, Department of Earth Science, University of Bergen, Norway*
*N. Pulido, Earthquake Disaster Mitigation Research Center, Japan*

Following the destructive earthquakes in 1999 in Izmit and Düzce, there is now an increased focus on risk mitigation in Istanbul. One of the fundamental aspects of this is to establish a reliable seismic hazard assessment in the area. Recent studies aiming to understand the behaviour of the North Anatolian Fault (NAF) in the Marmara Sea, have highlighted clearly that the earthquake hazard in Istanbul is mainly controlled by a relatively well-defined structure. Contributions from other segments of the NAF in the region are assumed to be insignificant as both the eastern and the western parts of the Marmara Sea have experienced recent earthquakes (i.e. 1912 Ganos and 1999 Izmit and Düzce earthquakes). Given these conditions, previous probabilistic seismic hazard assessments are not sufficient to account for the expected earthquake threat in the area. The recent ground motion simulations conducted using hybrid methodologies gave important insights about the variability of the ground motion in the metropolitan area of Istanbul and its surroundings. However, the uncertainties in the input parameters now force us to look carefully into our understanding of the fault behaviour in the Marmara Sea. Several input scenario models with various critical fault parameters are applied. The resulting ground motion distribution reveals the influence of source complexity. The most influential parameters are the geometry of the asperities, rupture initiation and velocity, rise time and stress-drop. Other important aspects are the geometry of the fault segmentation and linkage between the segments in individual earthquake ruptures. Assessing these critical parameters requires a detailed understanding of the source complexity. Paleoseismological studies of the fault ruptures during the 1912 Ganos and the 1999 Izmit and Düzce earthquakes therefore provide important clues on the expected fault behaviour in the Marmara Sea.

### SENSITIVITY OF GROUND MOTION SIMULATIONS TO EARTHQUAKE SOURCE PARAMETERS: A CASE STUDY FOR ISTANBUL, TURKEY – ID 1961

*M. B. Sørensen, University of Bergen, Norway*
*N. Pulido, NIED, Japan*
*K. Atakan, University of Bergen, Norway*

Following the disastrous earthquakes in Izmit and Düzce along the North Anatolian Fault in 1999, the earthquake hazard in the Istanbul area became a great concern. In this study we simulate strong-ground motions caused by a scenario earthquake (M=7.5) in the Marmara Sea, and investigate the effect of varying the input parameters on the broadband frequency ground motion. Simulations are based on a multiasperity source model that involves the combined rupture of the North Anatolian fault segments beneath the Marmara Sea. We use a hybrid model combining a deterministic simulation of the low frequencies (0.1-1.0 Hz) with a semi-stochastic simulation of the high frequencies (1.0-10.0 Hz). Computation at each frequency range is performed separately and the total ground motion is combined in the time domain. We calculate a total of 16 earthquake scenarios corresponding to

different source and attenuation parameters to study their effect on the ground motion. The most significant parameters in terms of ground shaking level are the rise time, rupture velocity, rupture initiation point and stress drop. The largest variability of strong ground motions is observed in adjacent regions to asperities and are associated with frequencies above 5Hz. For lower frequencies our simulated velocity spectra within the Istanbul area are fairly stable among scenarios.

### EARTHQUAKE SCALING AND NEAR-SOURCE GROUND-MOTIONS – ID 1873

*P. M. Mai, Institute of Geophysics, Switzerland*

This study analyzes catalogs of moderate-to-large earthquakes obtained in 3-D elastic continuous fault modeling governed by rate- and state-dependent friction. As a proxy for geometrical irregularities of the fault, we parameterize the frictional response of the system by including spatial distributions of the critical slip distance L. Fault zones at different evolutionarys stages are then characterized by variable range-of-size-scales present in the L-distibution.

Our earthquake-cycle simulations return large sets of model quakes whose source parameters show remarkable similarities when compared against observed earthquake source parameters. We investigate earthquake scaling relations on bulk source properties, and examine the characteristics of distributed slip on the fault plane. In particular, slip of large events (M > 6.5) is highly variable on the fault, while ruptures tend to start at the edges of asperities (regions of large slip), consistent with imaged finite-source rupture models.

Our investigations also show that the catalog of simulated source models provides a useful resource to generate physically self-consistent scenario earthquakes for near-source ground-motion prediction. Combined with the pseudo-dynamic source characterization to model the temporal rupture evolution, we use our event catalog to calculate near-field seismograms for a suite of scenario earthquakes. For a given target region, we therefore provide simulation-based ground-shaking maps that are useful for seismic hazard assessment. The large repository of physics-based near-source synthetics helps to investigate ground-motion variability for earthquake-engineering purposes.

### STRONG MOTION SIMULATION BY HYBRID GREEN'S FUNCTION METHOD: A GENERIC STUDY AND AN APPLICATION TO 2004 PARKFIELD EARTHQUAKE – ID 1693

*B. Sanli, Kandilli Observatory and Earthquake Research Inst., Turkey*
*E. Durukal, Kandilli Observatory and Earthquake Research Inst., Turkey*
*M. Erdik, Kandilli Observatory and Earthquake Research Inst., Turkey*

This study discusses the effectiveness of the hybrid Green's function method (HGF) in simulating near field strong ground motions. HGF method starts with calculating the synthetic Green's function which is a combination of deterministically calculated, low frequency motion and stochastically simulated, high frequency motion. Summation of Green's functions using the numerical framework of the Empirical Green's Function method gives the large earthquake synthetics. In the first part of the study we performed a generic simulation of strong ground motion that would emanate from a Mw 7.5 earthquake to test the applicability of the HGF method. Based on the comparison of results of this generic simulation with empirical attenuation relations and response spectra from several similar magnitude earthquakes, it can be stated that the method yields comparable results within the distance range 5-30km. There are unrealistically large amplitude differences between the two horizontal ground motion components for sites located at 1 km fault distance. However that is not evident in real recordings. Later, we simulated the Mw 6.0, 2004 Parkfield earthquake producing near-fault ground motion that favorably compares with the empirical data. We carried out simulations for the frequency range 0.1-25 Hz at eight rock and four soil site stations. Frequency dependent site amplification values are calculated using empirical data, and considered for the soil site simulations. The comparisons of simulated motion in time and frequency domain proved the efficiency of the HGF method in such broadband simulations.

## SC-C 1-II: Earthquake Source Complexity: From Geology Through Kinematic and Dynamic Models to Realistic Ground Motion Simulations

Thursday 13:30 - 15:00 – Room 18

### SOURCE CHARACTERISTICS OF THE 8 JANUARY 2006 (MW 6.7) INTERMEDIATE DEPTH KYTHERA EARTHQUAKE – ID 611

*C. Benetatos, Aristotle University, Greece*
*A. Kiratzi, Aristotle University, Greece*

The intermediate depth (h = 64 km) earthquake (Mw 6.7) of 8 January 2006 occurred close to the small island of Kythera at the western part of the Hellenic trench. The earthquake was strongly felt in all regions of Greece and in a very large area of the Eastern Mediterranean Sea, from Southern Italy to Egypt and Jordan. Most of thedamage was observed in the village Mitata of Kythera Island. The previous intermediate depth event in the same region occurred on 11 August 1903 (Mw 7.9) and caused similar damage to the village Mitata. We used teleseismic and regional broad band records to invert for the focal mechanism and the slip distribution on the fault. The regional moment tensor inversion revealed a reverse mechanism with considerable strike – slip component (NP1 strike=71O, dip=52O, rake=120O; NP2 strike= 207O, dip= 47O, rake=57O; Mo = 1.30E26 dyn-cm). This mechanism is in accordance with the regional stress field, at this depth range, where compression is NW-SE following the trend of the Hellenic trench. The inversion of the teleseismic data resulted in similar mechanism but the fit was significantly improved when we used two – sources in the modelling. The source time function lies in the range of 14 to 16 sec. The inversion of teleseismic records revealed that the moment was releasedin two main slip patches on the fault. Using stochastic ground motion simulation and the previously obtained slip on the fault plane we successfully predicted the observed near – field strong motion records. The uncorrected maximum accelerations of the nearest stations are 0.13g on the island of Kythira and 0.14g on Agios Nikolaos (southern Peloponnese). On Crete Island the uncorrected accelerations were of the order of 0.05g and in the more distant stations in Greece were an order of magnitude smaller.

### THE 2005 NOVEMBER 27 QESHM EARTHQUAKE (MW 6.4) IN THE PERSIAN GULF: BLIND THRUSTING – ID 1060

*M. Shahpasandzadeh, International Institute of Earthquake Engineering, Iran (Islamic Republic Of)*

Located at the south-eastern end of the Persian Gulf in the Strait of Hormuz, Qeshm Island is part of Zagros fold-and-thrust belt by the same geological features as the main land. In Zagros fold-and-thrust belt, most seismogenic activities are associated with active blind thrusting, which are not expressed by coseismic surface ruptures. Although frequent historical earthquakes, occasionally ranging up to Mw 7.7, have been documented in the Zagros-Qeshm region, but a few destructive earthquakes have been registered in the Qeshm Island during 20-21st centuries, none of which were associated with conspicuous co-seismic surface ruptures. Among documented historical earthquakes, the 1361 Qeshm (Mw 5.5, I0 VII+) earthquake, 18 February 1483 Hormuz strait (Mw 7.7) earthquake, April 1497 Hormuz (Mw 6.5, I0 VIII) earthquake, and 4 October 1622 Hormuz-Bandar Abbas earthquake

constitute the most prominent events in Qeshm Island. As the recent seismic activity of Qeshm Island, the 27 November, 2005 Qeshm (Mw 6, I0 VII) earthquake ruptured about 10 km of a fault, known as Qeshm fault, with an average vertical slip of 30 mm and with surface displacements up to 10 mm in places. This earthquake devastated about 24 villages with 10 dead and more than 100 casualties. Analysis of long-period seismic body waves shows that the earthquake ruptured a reverse fault dipping north-northwest at 38 ° to a depth of about 12 km. The main-shock was followed by an earthquake (Mw 5.5) six hour latter. The field evidences and focal mechanism solution of the second event show that a nearby normal fault with a strike of 308° and vertical dipping make it likely that its reactivation as a right-lateral strike-slip was triggered by the main-shock. The evaluation of blind active thrust faults and triggering earthquakes in the Zagros fold-and-thrust belts has beneficiary implications for the seismic hazard assessment.

### SOFT SOIL DEFORMATION DUE TO FAULT DISLOCATION IN BEDROCK USING MESHFREE METHOD – ID 1281

*A. Farahani, Tokyo Institute of Technology, Japan*
*A. C. Wijeyewickrema, Tokyo Institute of Technology, Japan*
*T. Ohmachi, Tokyo Institute of Technology, Japan*

In this paper fault rupturing during strong ground motion is simulated and the effects of faults on nearby structures are studied using the meshfree technique. The soft soil layers are modeled using the Radial Point Interpolation meshfree technique, and the bedrock is modeled with finite elements. When applying dynamic fault dislocation in the bedrock region using the split-node technique, some part of this region moves upward and pushes the soft soil layers. The split-node technique is used to introduce a displacement dislocation between adjacent elements. This paper investigates the effects of dip-slip angle, amplitude, speed and type of fault dislocation on ground deformation during fault rupturing and its effects on nearby structures. In order to simulate the non-reflecting far-field region for the system, time-varying absorbing boundaries have been used at the boundary nodes.

Keywords: fault rupture, meshfree, split-node technique, time-varying absorbing boundaries, Radial Point Interpolation method.

### RECORD SIMULATION BY THE EMPIRICAL GREEN FUNCTION METHOD USING A SOURCE WITH TWO CORNER FREQUENCIES – ID 1326

*M. Niño, ELSA, Joint Research Centre, Italy*
*M. Ordaz, Instituto de Ingeniería, UNAM, Mexico*
*A. G. Ayala, ELSA, Joint Research Centre, Italy*

The lack of complete catalogues of real earthquake records for the purpose of seismic design and evaluation of structures has made necessary the use of simulation procedures to generate synthetic catalogues. One of the most accepted simulation methods has been the empirical Green function method as it considers both the randomness of the problem and the physics of the source and the propagation path. In the application of this method, the Fourier transform of the acceleration spectrum of the signal originated at a source has been described using a single corner frequency however, recent studies have shown that the observed source acceleration spectrum is better fitted by an empirical source spectrum characterized by two corner frequencies, fa and fb. This paper is based on the original formulation of the empirical Green function method of the second author which improves the probability density function of the rupture time delays of the N cell in which the source of the simulated signals is divided. The scheme summation obeys the w2 scaling law at all frequencies approximating the extended area of the fault by a point source, whose rupture duration, is in accordance with its dimension.

One limitation in the application of the empirical Green function method in the simulation of signals to be used in the development of displacement based seismic design technology is the scarcity of records with good definition on the short frequency range. For this reason, in this paper a strategy to generate a small earthquake with this characteristic is illustrated by using a record of the same earthquake obtained from another site which has a better definition in the short frequencies range.

### CHARACTERISATION OF THE MICROSEISMICITY WITH NANOSEISMIC MONITORING IN THE REGION NORTH OF LORCA (SOUTH SPAIN) – ID 1999

*M. Häge, Geophysics, Germany*
*M. Joswig, Geophysics, Germany*

With the concept of Nanoseismic Monitoring the microseismicity was recorded to get information about the activity of local faults in the region north of Lorca (south Spain). The measurement was performed with two Seismic Navigating Systems (SNS), consisting of a small tripartite array with an aperture of 200m, respectively. Within 2 weeks we have registered more than 100 microearthquakes in the magnitude range ML = 1,6 to ML = -1,8. The sensitivity of the system is ML = -1 in 10km and ML = -2 in 3km distances. The flexibility and portability of the system allows investigating a spacious area and mapping systematic fault branches. First results show that the recent recorded seismicity and the paleoseismic information listed in tectonic maps do not inevitable correlate to each other. Cluster analysis and advanced localization techniques are applied to the data. The results will be related to the local tectonic frame.

### CAN GPS DATA CONTRIBUTE TO EARTHQUAKE SWARM STUDIES? – ID 1942

*V. Schenk, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*F. Mantlík, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*Z. Schenková, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*P. Kottnauer, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*Z. Fucík, Institute of Rock Structure and Mechanics AS CR, Czech Republic*

The Institute of Rock Structure and Mechanics in the frame of the Centre of Earth Dynamic Research activity is in the process of establishing the GEOdynamic Network of the Academy of Sciences (GEONAS). At the moment it consists of ten permanent GPS stations. Four of them monitoring GNSS satellite signals are located in the West Bohemia/Vogtland earthquake swarm region. The motion trends of this region and their probable irregularities caused by local seismogenic processes will be studied. The stations MARJ located near Jáchymov and POUS near Frantiskovy Lázne have been operating since 2003 and the other two LUBY near Cheb and KYNS in Kynsperk since 2005. The recorded high-resolution GPS data were processed by the Bernese software v. 5.0 with the aim of finding possible relations between occurrences of individual earthquake events and/or their swarms and long- or short-term motions of the Earth surface.

## SC-C 2-I: Recent Developments in Theoretical and Numerical Earthquake Source Dynamics: New Horizons to Predict Seismic Radiation and Near-Field Ground Motions

Thursday 15:30 - 17:00 – Room 18

### THE SCALE DEPENDENCE OF STRENGTH OF THE EARTH'S CRUST – ID 2077

*T. Heaton, California Institute of Technology, United States*

I discuss the implications of dynamic rupture with friction that has strong slip-velocity weakening. Although these friction laws are surprising, they seem to be an inescapable result of the observation that many faults are geometrically thin (less than several mm). Dynamic friction must be very low, or else the fault produces significant shear heating and subsequent melting. I demonstrate that strong slip-velocity weakening friction laws produce slip pulses that are very sensitive to perturbations in material properties and the pre-stress field. I hypothesize that, over many earthquake cycles, the Earth's crust evolves into a state of self-affine heterogeneous stress. I discuss how to build such a fractal stress tensor and I show that several aspects of seismicity can be explained by such a model. Normally we consider the strength of a material to be the stress at which yield occurs. However if the stress is heterogeneous, the determination of the strength of a material is not simply the maximum stress within the material. I extend the definition of "strength" to be the spatial average of heterogeneous stress over the length scale of failure. I show that with the assumption of a statistically stationary heterogeneous stress, that this average can be determined from the spatial power spectrum of the heterogeneous stress. Furthermore, I show that the average stress at which the crust fails depends on the length scale over which the averaging occurs. If the Earth's crust evolves into a stochastic state of stress and if the crust experiences failure at many length scales while in this stress state, then I show that "strength" must depend decrease with increasing length scale. Current indications are that the "strength" of the crust decreases from 100's of MPa at length scales of meters to 10's of MPA at length scales of kilometers.

## ASSESSMENT OF CONSTITUTIVE LAWS FOR THE SEISMIC FAULT – ID 16

*L. F. F. Miguel, Universidade Federal do Rio Grande do Sul, Brazil*
*J. D. Riera, Universidade Federal do Rio Grande do Sul, Brazil*

In addition to its unquestionable importance, the dynamics of rupture propagation is one of the most complex issues in Seismology. A constitutive criterion for the fault that correctly describes the relation between the static variables (normal and tangential stresses) and the kinetic variables (displacements and velocities) on the interface is needed for reliable predictions of the seismic motion in the epicentral region. In this paper, constitutive criteria commonly used in numerical solutions are initially examined, jointly with experimental results obtained by the authors for friction between solids. Some of these models are then evaluated by means of numerical simulation. Initially, the material is assumed elastic and homogeneous. Next, the influence of non-homogeneous material properties is evaluated by modeling density, Young's modulus and friction coefficient as correlated Gaussian random fields. The effect of fracture within the rock region adjacent to the fault is also numerically evaluated. Finally, the influence of rupture of protrusions (micro-asperities) between the sliding surfaces is analyzed. The influence of size on the form of the constitutive law or its parameters is assessed by means of Monte Carlo simulation. When the adjacent rock is assumed to be linearly elastic and homogeneous, no size effect is observed. Similarly, no significant size effect is detected for non-homogeneous rock. On the other hand, when the friction coefficient is characterized by a random field, a perceptible size effect is observed. Fracture occurrence in the region surrounding the fault does not cause significant modifications of the macro constitutive laws, it produces minor perturbations of the law determined without fracture. Finally, a macro constitutive criterion that takes into account the shear rupture of protrusions on the sliding surfaces is determined. The proposed modified velocity-weakening law, constitutes a more general and flexible constitutive criterion.

## EARTHQUAKE SOURCE CHARACTERISTICS FROM DYNAMIC RUPTURE WITH CONSTRAINED STOCHASTIC FAULT STRESS – ID 2052

*J. Ripperger, Inst. of Geophysics, ETH Zurich, Switzerland*
*J. P. Ampuero, Inst. of Geophysics, ETH Zurich, Switzerland*
*P. M. Mai, Inst. of Geophysics, ETH Zurich, Switzerland*

To predict ground motion for a future event, one of the challenging tasks is to anticipate its spatio-temporal rupture process. The source-rupture characteristics, in turn, are strongly correlated with the state of stress on an earthquake fault. Though the details of the incipient stress field can not be known, its overall statistical properties can be determined to some degree.

Our aim is thus to include the effects of rupture dynamics into earthquake scenario calculations by using a stochastic approach to characterize the initial stress field. Shear stress on the fault is modeled as strongly correlated random fields with von Karman distributions. The governing parameters of these distributions are the standard deviation std, the correlation length ac and the Hurst exponent H, describing the spectral falloff.

We have performed a parameter study to establish quantitative links between the stochastic stress parameters and the resulting characteristics of events in 3D dynamic rupture simulations.

## DYNAMIC SOURCE INVERSION BASED ON STABLE FORMULATION – ID 1539

*H. Goto, Kyoto Univ., Japan*
*S. Sawada, Kyoto Univ., Japan*

Source rupture processes has been reported for many large earthquakes. Their inversion methods are based on kinematic analysis. Because their analyses estimate all slip displacements as a function of time and space, it is difficult to solve inversion problems without constraints which cannot be explained on a physical basis. Previous results have been shown to be based nonphysical constraints on the rupture velocity, source time function, and total slip. A Dynamic source model satisfies the physical relationship between stress and the strain field on the fault plane. We posit that this dynamic source model introduces that physical relationship into source inversion analysis, and that space resolution is improved in the estimated model because the model is based on several time independent parameters; initial stress, yield stress, residual stress, and slip weakening distance. We propose a new source inversion method based on a dynamic source model. Because a small change in yield traction produces undesirable sensitivity, rupture time is used as the governing parameter to avoid such sensitivity. Three independent variables, selected as estimation parameters in the inversion analysis, are called consolidated dynamic parameters, and consist of rupture time, slip-weakening distance, and dynamic stress drop. A multi-scale approach to dynamic source inversion analysis was introduced in which the number of estimated values and the observation frequency ranges increase as the scale changes. Resolution of the analysis is the divided number when the estimated results are similar to those of the next scale model. The distribution of the observation sites was shown to affect the resolution of the estimated results.

## TOWARDS THE EARTHQUAKE MECHANISM: A SIMPLE MODEL OF SEISMIC SOURCE DYNAMICS – ID 1127

*A. Grigorian, ARSAT Center, Armenia*

Present paper considers our outlook on earthquake phenomenon as criticality and physico-chemical nonlinear oscillation occurring in active medium. The paper considers a conception of possible seismic source origin and its further evolution, based on some results of theory of branched chain processes and analysis of nonlinear dynamical systems. A process with very long induction period and abrupt pulse generation one may describe by a sequence of initiation, propagation and termination stages. Criticality, as well as various regimes of pulse generation and nonlinear oscillations, is shown to be a result of nonlinear feedback. The results are compared with laboratory experiments on shear deformation of loaded solids at low temperatures using Bridgman's anvil, and some other mechano-chemical experiments, accompanied by detonation-type explosion. To simplify the model as much as possible, the seismic source (a localized pulse generator - oscillator) and ambient media for seismic wave propagation are assumed separated in space. These make it possible to deal with a set of ordinary differential

equations, describing the branched-chain process, and utilize the feedback theory to design the simplest structure of the model with minimum of nonlinearities and necessary positive and negative feedback. Further complication makes it possible to simulate wave propagation, too. The following hypothetic scenario is considered. Strain in rock within the localized area of the earthquake epicenter results in accumulation of internal energy (like a laser pumping). This process is accompanied by slow alteration in physico-chemical properties. At some critical conditions, a small shift in kinetic equilibrium of active centers can result in rapid energy dissipation via seismic wave. Shear deformation by tectonic origin is most important for shallow and moderate depth earthquakes. The model is independent of physical state of considered media (solid-to-gas) and can describe some other processes of practical interest, e.g. load aging and elastic-plastic rupture of materials.

## SC-C 2-II: Recent Developments in Theoretical and Numerical Earthquake Source Dynamics: New Horizons to Predict Seismic Radiation and Near-Field Ground Motions

Thursday 17:15 - 18:15 – Room 18

### SOME INSIGHTS ON DYNAMIC RUPTURE MODELLING USING A FINITE ELEMENT METHOD – ID 856

*S. Bernardie, BRGM, France*
*H. Aochi, BRGM, France*
*H. Modaressi, BRGM, France*
*R. Madariaga, ENS, France*

Finite element methods (FEM), as often used in soil dynamics, should be a powerful tool to simulate the dynamic rupture process on earthquake faults, allowing us to take into account the asymmetry of fault geometry with respect to the ground surface as well as material heterogeneity and inelastic phenomena. A FEM program to model non-linear elastodynamics, GEFDYN, is used to model rupture propagation. The fault is simulated using "joint-elements" that are thin and flat and may be programmed to simulate a number of frictional properties. We perform preliminary simulations on a single plane fault embedded in a 2D homogeneous unbounded elastic media and compare results with those of a boundary integral equation method. Under uniform initial stress conditions, we release certain amount of stress on a small area of the fault and the dynamic rupture progresses spontaneously controlled by the plastic behaviour of joint-elements used to simulate the Coulomb friction law on the fault. The formulation of the joint elements, as well as the parameters of their constitutive model are analysed and discussed, such as the shear elastic modulus G and the initial thickness of the joint. We find it important to carefully treat these joint-elements to obtain the accurate solutions. With these tests, we demonstrate that this tool constitutes an appropriate model to study dynamic rupture propagation on a fault.

### HIGH FREQUENCY SOURCE PROCESS INFERRED FROM NEAR-FAULT GROUND MOTIONS – ID 814

*N. Pulido, National Res. Inst. for Earth Sc. and Dis. Prev., Japan*
*L. Dalguer, Dep. of Geol. Sc., San Diego State Univ. CA, United States*

Simple dynamic crack models have theoretically demonstrated that strong variations of the rupture velocity at the crack boundaries are responsible for most of the high frequency (HF) source radiation. For large earthquakes, strong heterogeneity in rupture velocity during the fault rupture progression may have a large contribution to the HF ground motion generation. To address this problem we have investigated a spontaneous dynamic fault rupture process of the 2000 Western Tottori prefecture earthquake (Japan), by using a 3D-FDM scheme coupled with a slip weakening friction law. To infer the HF radiation we calculate the far-field acceleration spectra (FFS), represented by the gradient of rupture velocity across the fault plane multiplied by the dynamic stress drop distribution from the dynamic model. Calculation of this product for the Tottori earthquake suggests that HF is radiated from regions in the fault plane where a large rupture velocity gradient is overlapped by a strong dynamic stress drop. In this paper we infer the HF source radiation from near-fault ground motions. HF ground motions are calculated as an incoherent rupture of cracks evenly distributed across the fault plane. Rupture times of cracks are constrained by results of the dynamic model. HF ground motion at every site is obtained by convolving Empirical Green's Tensor Derivatives (EGTD), with the slip velocity function at each crack. Slip velocity functions are obtained from the dynamic model by modifying their acceleration Fourier spectra amplitude to allow for a variable FFS and fmax, which are set as models parameters. These parameters are obtained by a GA inversion scheme to optimize agreement to observed HF ground motions. EGTD are obtained from a set of clustered events by a linear inversion scheme. EGTD accurately describe an average propagation path between each station and a focal zone corresponding to mainshock asperities.

### VALIDATION OF A NEW HAZARD SCENARIO (MAXIMUM PARTICLE DISPLACEMENTS); NORTHRIDGE, 1994. – ID 388

*L. Sirovich, Istituto Nazionale O.G.S., Italy*
*F. Pettenati, Istituto Nazionale O.G.S., Italy*

We extended our kinematic "KF" approach for calculating seismic scenarios to obtain also regional patterns of maximum particle displacements (PGD) of earthquakes. For some years, we used our "KF" formula to perform intensity-based source inversions of earthquakes (B.S.S.A., 93, pp. 47-60; B.S.S.A., 94, pp. 1737-1747; J.G.R., 109, 2003JB002919, 2004) and, very recently, to produce intensity hazard scenarios in a parametric, deterministic-Montecarlo, way (see this Conference, and also Eos, Transactions, 85, 47, F1391). We were not surprised by the possibility of using "KF" also for PGD scenarios because our original model calculates the S-wave radiation in dimensionless form, that, however, is conceptually related to the displacement in the source. The present test was conducted on the Northridge, 1994, earthquake. For this, we used the PGD values provided by the following U.S. Agencies and Universities: USGS, USC, DWP, CDMG (now California Geological Survey). In our parametric approach, we used 52,974 sources, which included all sources which were suggested by the authors who treated instrumental measurements, independently from our work. Note that the central source used by our parametric calculations occurred to lie close to the source found by Wald et al. (1996). In each point of the Great Los Angele Region, we calculated the mean PGD given by the 52,974 sources, and its standard deviation. Then, we compared our syntetic PGD regional pattern with the 158 PGD values obtained by strong motion recordings. The result was satisfactory, a mismatch in the NE direction excepted. This is clearly due to the fact that the study earthquake showed clear up-dip directivity, which is not reproduced by our simple model. Hopefully, the PGD scenario for an earthquake with more horizontal directivity woul be more satisfactory (as in theLoma Prieta, 1989 case, that we also treated in this Conference).

### THE DIFFERENCES OF FAULTING AND NEAR-SOURCE GROUND MOTION OF LARGE AND SMALL EARTHQUAKES DEPICTED FROM DYNAMIC RUPTURE MODELS – ID 1781

*L. Dalguer, San Diego State University, United States*
*S. M. Day, San Diego State University, United States*
*H. Miyake, ERI, University of Tokyo, Japan*
*K. Irikura, DPRI, Kyoto University, Japan*

Small earthquakes rarely break the free surface, and occur more often than large earthquakes, while large earthquakes present opposite characteristics. In addition, recent observations

suggest that small earthquakes generate stronger ground motion than large earthquakes in the frequency range of around 1 Hz. These observations indicate differences in the rupture mechanism of large and small earthquakes. We explore the mechanism of earthquakes by means of numerical models and propose characteristic dynamic models for practical application to strong ground-motion prediction. The characteristic models consist of asperity and surrounding background areas for surface (large) and subsurface (small) earthquakes. These models show that surface earthquakes are characterized by a large area of negative stress drop surrounding the asperities, while sub-surface earthquakes present positive or zero stress drop. The source scaling of seismic moments and rupture area derived from the asperity models is consistent with empirical models if the sub-surface earthquakes follow self-similar scaling and surface earthquakes break this self-similarity. We apply the proposed characteristic asperity models to simulate near-source ground motion, and we find that hypocenter location below the asperity can produce strong directivity of the slip velocity function toward the free-surface. That effect, in addition to a reduced fault area and low fracture energy during rupture may be significant in enhancing high-frequency ground motion. On the other hand, large earthquakes are characterized by shallow hypocenter (upper part of asperity), large fracture energy on the asperities and enhanced energy absorption due to large areas of negative stress drop in the background area. The existence of negative stress drop can be a manifestation of large area of damage zone off-fault where energy is dissipated. These characteristics of large earthquakes inhibit severe directivity effects on the slip velocity function directly toward the free-surface reducing the high-frequency ground motion.

## SC-D 1-I: 2-D and 3-D Crustal Models of Europe

Wednesday 13:30 - 15:00 – Room 7+8

### P AND S SEISMIC VELOCITIES BENEATH THE ITALIAN PENINSULA FROM LOCAL EARTHQUAKE TOMOGRAPHY – ID 1828

*D. Scafidi, University of Genova, Italy*
*S. Solarino, INGV, Italy*
*C. Eva, University of Genova, Italy*

We investigate the P and S waves velocity structures and the Vp/Vs ratio beneath the Italian peninsula down to 100 km depth by seismic travel time tomography. Our aim is not only to define and confirm the gross structural framework of the crust and of the upper mantle, which is somewhat already known, but, in particular, to provide more details either on the shape of the complex subduction that acts on the peninsula either on the transition zones between continental and oceanic crusts. The experiment is based on data published by the International Seismological Centre (ISC). More than 60.000 P phase readings and about 25.000 S phase readings for the period 1997-2005, as recorded by various seismic networks around the italian peninsula, have been inverted employing SIMULPS, the well constrained and worldwide adopted tomographic code. The joining of an adequate dataset and the introduction of some alternative strategies in the travel time tomographic routine (grid designing, ray tracing of the forward problem, appropriate data selection) results in a fair cross-firing all over the large inverting area and partly ensures ray sampling also for deeper layers. Although results are partly biased by the uneven resolution of the tomographic images and by the varying maximum resolved depth, we discuss the structural framework of the most debated areas of the peninsula as they appear from our Vp and Vs 3D inversion. In particular, a very shallow Moho is evident in the Ligurian Sea; a gentle subduction is visible under the western Alps; in the eastern Alps, an opposite dip direction of high-velocity mantle material would suggest that an Adriatic moho subducting under an European one should be further discussed. Finally, the slab of the Calabrian arc is confirmed as very steep in the Tyrrhenian Sea.

### 3-D SHEAR VELOCITY MODEL OF THE UPPER MANTLE BENEATH THE AEGEAN SEA (GREECE) – ID 1822

*I. Kassaras, University of Athens, Greece*
*F. Louis, University of Athens, Greece*
*A. Magganas, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*
*G. Kaviris, University of Athens, Greece*

The purpose of this work is to obtain a 3-D shear velocity model of the upper mantle beneath the Aegean. In a previous work, averaged phase velocities of fundamental mode Rayleigh wave were determined along 36 interstation profiles across the Aegean in the period range 10-100 s. Phase velocities were further inverted to produce 1-D path average shear velocity models. The interpolation of these models yielded a 3-D image of wavespeed lateral variations throughout the Aegean area. However, due to the irregular distribution of ray paths in the region and the limited dataset, simple interpolation could not provide stable results for the large-scale lateral velocity variations, or constraints on the resolution of the model. This dataset is combined in a continuous regionalization tomographic scheme, to derive a smooth model of lateral shear velocity variations and a qualitative estimation of the model constraint as a function of geographical position. The observations reveal significant velocity variation between continental Greece (low velocities) and the Aegean Sea (high velocities). A low velocity zone is observed beneath the North Aegean Trough. In South Aegean high velocities indicate the subducted African lithosphere beneath the Aegean. Low velocity zones are associated with regions of high extensional strain rates, recent volcanism and high heat flow. These observations suggest a hot or perhaps partially molten upper mantle and/or distributed deformation of the upper mantle beneath this region, probably related with the slab roll-back that has accompanied back-arc extension. ACKNOWLEDGMENTS The present study was funded through the program EPEAEK II in the framework of the project "Pythagoras - Support of University Research Groups" with 75% from European Social Funds and 25% from National Funds", contract No. 70/3/7306.

### QLG TOMOGRAPHY IN BRITAIN – ID 1740

*S. Sargeant, British Geological Survey, UK*
*L. Ottemöller, British Geological Survey, UK*

Lateral variations in Lg-wave propagation in and around mainland Britain have been investigated using short period recordings from the UK Seismic Network. The dataset consists of 30 crustal earthquakes (2.7-4.7 ML) recorded in the distance range 170-600 km giving a total of 510 ray paths. The study area is generally well sampled with the exception of northernmost Scotland and southeast England. The regional average Lg quality factor, QLg, was estimated between 0.5 and 7.0 Hz. The result indicates that attenuation in mainland Britain is similar to levels observed in France and provides valuable information for ground motion simulation in the UK. The lateral variation in QLg was solved as a mixed-determined inverse tomography problem following the methodology of Ottemöller et al. (2002). Tomographic inversions were conducted individually for 23 frequencies in the range 0.5-7.0 Hz. The spatial resolution obtained was around 100 km in areas with good data coverage. Lower than average QLg values were obtained for the collision zone associated with the closure of Iapetus, which lies between the Highland Boundary Fault and a major shear zone in northern England. Low QLg values were also obtained for the Anglo-Brabant Massif region whereas the older Welsh Massif appears to be characterised by high QLg. The results point towards similar attenuation north and south of the Great Glen Fault in Scotland and the Variscan Front in southern England but these areas are not well resolved.

### AUTOMATIC SEISMIC PHASE PICKING AND CONSISTENT ERROR ASSESSMENT FOR LOCAL EARTHQUAKES IN THE ALPINE REGION – ID 1762

*T. Diehl, Institute of Geophysics ETH, Switzerland*
*E. Kissling, Institute of Geophysics ETH, Switzerland*
*S. Husen, Swiss Seismological Service, Switzerland*
*N. Deichmann, Swiss Seismological Service, Switzerland*
*F. Aldersons, MIES, Switzerland*

The detailed study of the Alpine lithosphere structure by local earthquake tomography requires the compilation of a data set covering the whole greater Alpine region. In a first approach, Solarino et al. 1997 compiled phase data from most national and regional networks in the Alps and surrounding areas. The minimum uncertainty of ±0.2 s (average uncertainty approx. ±0.3 s neglecting possibly large systematic errors due to phase misidentifications) for the merged phase data was sufficient to resolve only large-scale anomalies such as the Ivrea body in the Western Alps. To improve our knowledge of the detailed 3D crustal structure, in particular the structure of the lower crust, we need to compile a data set of P- and S-wave arrivals, which is consistent, of high quality (average uncertainty approx. ±0.1 s), and (very) large. Therefore, to reduce the number of outliers (mispicks and phase misidentifications), we repick the waveform data again. In our approach, we compile and merge waveform data of the Alpine region for events with Ml $\geq$ 2.5 (reported by different seismic observatories, data set complete for Ml $\geq$ 3.0), including records from permanent networks in Austria, France, Germany, Italy, Slovenia and Switzerland. The goal of a consistent and large data set can only be reached by the application of an automatic picking tool. In our approach, we use the "MannekenPix"-tool of Aldersons (2004), which includes an automatic quality-weighting scheme. A manually picked reference data set is used for the calibration of the automatic picking tool. To assure the consistency of this reference data set, we apply a predefined phase picking and error assessment system to the hand picking procedure. Finally, we present preliminary tomography results.

### P WAVE VELOCITY PERTURBATIONS OF THE CRUST BENEATH GEORGIA – ID 1414

*T. Mumladze, United National Survey of Seismic Protection, Georgia*

In this study was determined the first high-resolution tomographic image of the crust beneath Georgia applying the local tomography method of Zhao et al. (1992). The study area was divided into four layers vertically and a 3-D grid net was set up in the modeling space. Velocities at grid nodes were taken as unknown parameters. The velocity at any point in the model was computed by linearly interpolating the velocities at the eight grid nodes surrounding that point. The grid spacing was 30 km in the horizontal and 5 to 20 km in the vertical direction, respectively. We used 78,454 P and 67,105 S wave arrival times from 6750 earthquakes recoded by 98 seismic stations of the regional seismic network of Georgia and seismic networks of Azerbaijan and Armenia. Our results show strong lateral heterogeneity in the crust under Georgia and correlation among the velocity variations, seismicity, active faults, and Quaternary volcanic centers. Our tomography image of the uppermost mantle reflects the depth variation of the Moho discontinuity.

### SURFACE WAVE GROUP VELOCITY TOMOGRAPHY OF THE QINGHAI-TIBET PLATEAU – ID 1819

*Y. Chen, Institute of Geophysics, China*
*J. Badal, University of Zaragoza, Spain*
*J. Hu, Institute of Geophysics, China*

More than 660 earthquakes generated fundamental mode Rayleigh and Love waves whose vertical and horizontal components were corrected for instrument response and their respective traces reduced to ground motion. Using Frequency-Time Analysis and clustering, we have obtained group velocity dispersion curves for more than 1,500 Rayleigh and 1,450 Love great-circle source-receiver paths and periods ranging from 10.4 to 95.3 s. After inverting the path-averaged group times by means of a tomographic method and a stochastic scheme, we have retrieved location-dependent group velocities on a discrete 2ox2o grid and constructed group velocity tomographic maps for Rayleigh and Love waves at ten typical intermediate periods. The tomographic images of the Qinghai-Tibet Plateau show significant group-velocity variations as laterally as with depth revealing the complexities of the regional lithosphere and uppermost mantle. Surface waves become more sensitive to sedimentary basins at periods shorter than 20 s for Rayleigh waves and 30 s for Love waves, and to crustal thickness and average crustal velocity at intermediate periods, 30 60 s for Rayleigh waves and 50 70 s for Love waves. Slow-velocity anomalies at the shortest periods correlate well with large sedimentary areas, whilst relatively high velocities appear associated with mountain belts and transition zones. The junction formed by the subduction of the Indian Plate beneath the Eurasian Plate is clearly imaged by a low-velocity band. Fast-velocity anomalies at the longest periods are consistent with the tectonic blocks and sutures peculiar to the plateau, and they show the effects of plate interaction.

## SC-D 1-II: 2-D and 3-D Crustal Models of Europe

Wednesday 15:30 - 16:30 – Room 7+8

### A NEW SEISMIC MODEL OF THE EASTERN ALPINE CRUST – ID 869

*M. Behm, Institute of Geodesy and Geophysics, Austria*
*E. Brückl, Institute of Geodesy and Geophysics, Austria*
*M. Grad, Institute of Geophysics, Poland*
*Celebration 2000 & Alp 2002 Working Groups, Other*

During the last years, the Eastern Alps and their transition to the surrounding provinces (Bohemian Massif, Pannonian Domain, Southern Alps/Dinarides) have been investigated by the WAR/R experiments CELEBRATION 2000 and ALP 2002. The observation geometry of these experiments enables both 3D and 2D inversions. The 3D inversion covers the abovementioned regions and has an extension of approximately 600 x 660 km. About 78,000 traces were used to derive a 3D P-wave velocity model of the crust and a Moho depth map. The inversion methods are based on a combination of innovative stacking techniques and traditional 3D tomography. 2D modelling was performed along several profiles by interactive ray tracing. TRANSALP and several vintage profiles provide additional constraints to the models.

In general the 3D and 2D models agree very well. The different characteristics of the 2D and the 3D approaches are discussed, focussing on accuracy and resolution. A final model is derived by combining 3D and 2D results. This new seismic model provides a sound basis for tectonic interpretations. In this study we concentrate on seismological applications of the model and demonstrate its potential for hypocentre relocation and travel time corrections for teleseismic studies.

### LITHOSPHERIC STRUCTURE OF THE WEST-PANNONIAN BASIN, BASED ON CELEBRATION 2000 3D SEISMIC DATA – ID 532

*T. Fancsik, ELGI, Hungary*
*G. Falus, ELGI, Hungary*
*Z. Hajnal, USASK, Canada*
*R. Keller, UTEP, United States*
*A. C. Kovacs, ELGI, Hungary*
*I. Török, ELGI, Hungary*
*E. Hegedus, Elgi, Hungary*
*A. Guterch, Polish Academy of Sciences, Poland*
*M. Grad, University of Warsaw, Poland*

In the last decades, modern and geochemical research,

has brought to light several of the fundamental tectonic complexities of the Pannonian Basin. One of the most significant and up-to-date database available for the investigation of the deeper segments of the Pannonian Basin System is the data collected by the CELEBRATION 2000 multinational program. This novel 3D deep seismic experiment allowed the comprehensive investigation of a major segment of Central-Europe but was sufficiently detailed for a more inclusive study of this portion of the Pannonian Basin System. Utilizing this regional data set, a 3D seismic tomographic inversion of the whole crust and the uppermost mantle of the investigated area became possible. Potential field geophysical data, although with somewhat restricted penetration depth, can also carry significant geological information. Besides the geophysical methods, geochemical and microstructural analysis of xenoliths samples, which carry direct information from the deep crust and upper mantle also play an important role in this integrated study of the lithosphere of the region. This paper deals with the structural definition and characterization of the Transdanubian Central Range (TCR) tectonic unit, one of the best studied areas of the western Pannonian Basin. Despite the large number of geophysical, geological and structural geological studies the origin of the TCR is still not satisfyingly cleared. This work attempts to review previous, contrasting ideas about the origin of the TCR in the light of the newest geophysical and geochemical data assembled in the last decade in order to determine the horizontal and vertical dimensions and geometry of the TCR, which has fundamental effects on its possible origin and history during the evolution of the Pannonian Basin.

### NEW HIGH-RESOLUTION MARINE WIDE-ANGLE SEISMIC PROFILES ALONG THE HATTON CONTINENTAL MARGIN AND IN THE PORCUPINE BASIN, WEST OF IRELAND: A CASE STUDY – ID 2016

*P. W. Readman, Dublin Institute for Advanced Studies, Ireland*
*B. M. O'Reilly, Dublin Institute for Advanced Studies, Ireland*
*P. M. Shannon, University College Dublin, Ireland*
*J. Makris, GeoPro GmbH, Germany*
*C. Ravaut, Dublin Institute for Advanced Studies, Ireland*
*A. Chabert, Dublin Institute for Advanced Studies, Ireland*
*F. Hauser, University College Dublin, Ireland*
*L. Gernigon, University College Dublin, Ireland*

Results from two marine wide-angle seismic surveys west of Ireland are presented. The work continues the series of RAPIDS (Rockall and Porcupine Irish Deep Seismic) projects. HADES (Hatton Deep Seismic) investigates the volcanic Hatton Basin and Continental Margin, while RAPIDS4 indicates a non-volcanic affinity for the older (early Mesozoic) Porcupine Basin. These latest experiments represent a major advance in resolution of deep structure, with up to one hundred ocean bottom seismometers deployed along each profile, at a spacing of about 3 km. Airgun sources fired at about 100 metre intervals along the experiment profiles have produced a huge amount of data. A combination of forward modelling and tomographic inversion techniques were applied to the data and yield detailed information about velocity structure to mid/lower crustal and upper mantle levels. The new results from HADES have improved our knowledge of the crustal and upper mantle structure in the North Atlantic region. They have added considerable detail to the structure of high velocity bodies located at the ocean-continent boundary that has general implications for understanding volcanic passive margins. The RAPIDS4 experiment in the Porcupine Basin indicates that its crustal structure is highly asymmetrical with anomalous upper mantle velocities interpreted as partially serpentinised peridotites, similar to those inferred in the Rockall Basin. This case study illustrates that without recent advances in wide-angle seismic acquisition technologies, processing and interpretation strategies, our capability to understand the development of passive margin and extensional basin systems would be severely hampered. The Irish Petroleum Infrastructure Programme and the Geological Survey of Ireland have funded the HADES and RAPIDS4 projects.

### SEISMIC MODELS AND CRUSTAL STRUCTURE MAPS OF EUROPE – ID 1680

*M. Grad, University of Warsaw, Poland*
*D. Booth, British Geological Survey, UK*
*T. Tiira, University of Helsinki, Finland*

From the early 1970s, many good crustal models have been produced for different regions in Europe. Most crustal structure models describe the variation of seismic parameters, since seismic techniques provide the best resolution of discontinuities. From the point of view of the quantity of high resolution data and models now available, particularly seismic models, it is an appropriate time to bring them together and produce new integrated crustal structure maps of Europe, understand as an area from Ural Mountains in the east to mid-Atlantic ridge in the west, and Mediterranean Sea in the south to Spitsbergen in Arctic in the north. Why improve crustal structure maps? To improve the maps, we need to improve the structural models from which they are drawn, by integrating the best local models available. An optimum crustal structure model is required for at least these four reasons: (1) as a pointer to the tectonic processes shaping surface geology; (2) to improve accuracy of location of earthquakes and explosions; (3) to understand and predict regional anomalies in seismic wave propagation, and (4) to allow removal of crustal effects in tomographic modelling of the mantle. European institutions have organized or participated in several significant collaborative or individual experiments in recent years, including POLONAISE'97, EUROBRIDGE, TOR, SVEKALAPKO, CELEBRATION 2000, ALP 2002, SUDETES 2003, ALPASS and PASSEQ, as examples. The models derived from them are of particular interest. The ESC Subcommission on Crust and Upper Mantle structure has proposed a project aimed at producing updated maps of European crustal structure, particularly in terms of seismic parameters, such as Moho depth and average crustal P- and S-wave velocities, anisotropy and upper mantle velocity acquired through deep seismic sounding, receiver function and tomographic analysis. We will present preliminary maps for several parts of Europe, as well as for the whole Europe.

## SC-E 1: Earthquake Forecasting and Society

Wednesday 10:45 - 12:15 – Room 18

### LESSONS LEARNED FOR EARTHQUAKE PREDICTION FROM FORESHOCK-AFTERSHOCK ANALYSIS: THE EARTHQUAKE SEQUENCES OF OCTOBER-NOVEMBER 2005, AEGEAN SEA, AND APRIL 2006, IONIAN SEA, GREECE – ID 1990

*G. Papadopoulos, Institute of Geodynamics, National Observatory, Greece*
*E. Daskalaki, Institute of Geodynamics, National Observatory, Greece*
*A. Fokaefs, Institute of Geodynamics, National Observatory, Greece*
*M. Kolligri, Institute of Geodynamics, National Observatory, Greece*
*G. Minadakis, Institute of Geodynamics, National Observatory, Greece*
*K. Liadopoulou, Institute of Geodynamics, National Observatory, Greece*
*K. Orfanogiannaki, Institute of Geodynamics, National Observatory, Greece*
*A. Pirentis, Institute of Geodynamics, National Observatory, Greece*

Three strong earthquakes occurred near Samos Island, Aegean Sea, on 17 October (ML 5.4 and 5.5) and on 20 October 2005 (ML5.6). On 18 October 2005 another strong (ML5.6) earthquake occurred near Zakynthos Island, Ionian Sea. The Zakynthos seismicity increased again during April 2006. Nine strong shocks of ML4.7 to ML5.4 were recorded from 03.04.06 to 19.04.06 with the largest two (ML5.4) occurring on 11.04.06 and

12.04.06. Both sequences caused serious social problems. However, in real-time conditions it became impossible to discriminate between foreshocks-mainshock-aftershocks. Retrospective analysis of the standard catalogue showed that in Samos foreshock activity started on 17 October 2005. The analysis of the Samos station (SMG, epicentral distance 50 km) records revealed a set of 50 small early foreshocks occurring from 12 to 17 October 2005 recorded only in SMG. For the Samos shocks listed in the standard catalogue for the period October-November 2005 a relationship was established between duration magnitude, MD, and signal duration, D, in SMG. Then, MD was obtained from D for the early foreshocks. The statistics (b-value, seismicity rate) for foreshocks (period from 12 to 20 October) and for aftershocks (20 October to 21 November 2005) indicates that the 20 October 2005 event was the mainshock. A similar procedure, applied to the Zakynthos sequence of April 2006, concluded with the retrospective discrimination between foreshocks-mainshock-aftershocks. These examples show that should an automated system of daily monitoring of the seismicity parameters variation was in operation, the evaluation of the nature of the activity in real-time conditions would be helped substantially. In addition, such a system would be of value to support authorities in making decisions. The progress in creating such an automated system for the daily monitoring of seismicity variations all over Greece is presented.

## AN INTERNET BASED EARTHQUAKE FORECAST PERFORMANCE EVALUATION SYSTEM – ID 1629

*B. Ustundag, Istanbul Technical University, Turkey*
*O. Gundogdu, Istanbul University, Turkey*
*H. Eyidogan, Istanbul Technical University, Turkey*

A major concern of the earthquake forecast studies is objective and comparable measurement of the performance. We developed an Internet based performance measurement mechanism that also provides secondary methods based on voting by the most successful forecasting methods in order to increase correlation to the earthquakes. The system mainly measures the positive and negative correlation with respect to normal seismicity rate of the selected region. Regional seismic probability spectrum is represented by a distribution function. Variables of the probability distribution function are set with respect to earthquake catalogue and it is updated with the recent events. Each project or amateur subscribes to the system and they can not change the method during evaluation period. Subscribed methods are called players and the system is called "earthquake forecast league" in order to provide continuous motivation in long term. Players do not see the magnitude and location predictions until the end of forecast period. Computer has random players who forecast the earthquakes with respect to different random distributions. Players do not know who the artificial random players are since they use their nicknames. Each forecast requires a term length & beginning date, magnitude level and simplified rectangular location selection. As a result of relative probabilistic performance measurement mechanism, predicting the rare events with smaller target area and magnitude error provides higher points. These error level oriented calculation method is constructed so that normal probability yields zero and logarithmic Richter magnitude scale is satisfied. Each forecast has a cost that limits infinite number of forecasts. A rule set is applied to prevent homogeneity of the criteria for such specific cases as high normal seismicity of aftershock periods. Several amateurs applied in the first period. Besides the scientific purposes of this study, we determined important social benefits.

## FIRST VERSION OF MAP OF EXPECTED EARTHQUAKES FOR KURIL ARCH : COMPARISON WITH WORLD-WIDE MEE TEST – ID 240

*A. Zavyalov, Institute of Physics of the Earth, Russian Federation*

The report continues a series of papers devoted to results of MEE algorithm test in seismoactive regions of the world received during 1985-2002. In this work the Kuril regional EQ catalog was used. Previously it was established, that cutoff energy class K=9.5. Series of Maps of Expected Earthquakes for the period from 1970 to 2001 with 3 months shift were designed. Earthquakes with K>=13.5 were considered as target events. Maps of Expected Earthquakes (MEE) were constructed on a basis of distributions of density seismogenic faults Ksf, a slope of recurrence curve b-value, density of the seismic events flow N, realized seismic energy E2/3. For each prognostic attribute values of retrospective statistical characteristics have been received and levels of alarm to each attribute are chosen. The average waiting time of strong earthquake (K>=13.5) appeared equal Texp=3.40+/-1.27 years. The unconditional probability of strong earthquake occurrence during Texp has been designed. It appeared equal P(D1)=0.0720. A series of MEE for region of the Kuril island arch has been designed with step dt=3 months. The analysis of all set of received MEE for the Kuril island arch has shown, that the efficiency of algorithm MEE at the retrospective forecast of strong earthquakes of region is not worse than similar parameters on earlier investigated seismoactive regions of the world: about 68% of strong earthquakes occurs in zones with conditional probability level P(D1|K)>=70%, and the average area of alarm zones thus makes about 30% from the area of supervision. Results of the research show that the proposed MEE algorithm and the Maps of Expected Earthquakes might be recommended at present to strengthen observations over short-term precursors at zones of high conditional probability and to take preventive measures on order to mitigate damage from the future strong earthquakes. The work had financial support of RFBR grant 05-05-08022.

## SEISMIC SOURCE ZONES IN PSHA: ALEATORY OR EPISTEMIC? – ID 430

*K. Coppersmith, Coppersmith Consulting, Inc., United States*
*R. Youngs, Geomatrix Consultants, Inc., United States*

Since the inception of probabilistic seismic hazard analysis (PSHA), seismic source zones have been the most common tool used to represent the locations of future earthquakes. This is especially the case in stable continental regions where active faults are difficult to identify. But what do seismic source zones represent? In some implementations they define an area where earthquakes may occur randomly in space - an aleatory model. In others, they represent an area where unknown but suspected faults may lie - an epistemic model. Likewise, what do the boundaries of source zones represent? Are they physical limits to rupture? Do they separate regions having differing rates of seismicity? Understanding these different interpretations could mean that representing them in PSHA should be done in different ways. This paper examines these alternative interpretations of seismic source zones and their implications to PSHA. It provides examples and recommendations for developing seismic source zones to represent varying interpretations. Examples will be given from site-specific and regional PSHAs conducted in Europe, eastern U.S., and other parts of the world.

## LESSONS LEARNED - THE USE OF FORMAL EXPERT ELICITATION IN PROBABILISTIC SEISMIC HAZARD ANALYSIS – ID 1270

*K. Coppersmith, Coppersmith Consulting, Inc., United States*
*R. Youngs, Geomatrix Consultants, Inc., United States*
*R. Perman, Geomatrix Consultants, Inc., United States*

Probabilistic hazard assessments provide the opportunity, indeed the requirement, to quantify the uncertainties in important inputs to the analysis. The locations of future earthquakes, their recurrence rates and maximum size, and the ground motions that will result at a site of interest are all quantities that require careful consideration because they are uncertain. The earliest PSHA models (Cornell, 1968) provided solely for aleatory variability in these quantities. The most sophisticated seismic hazard models today, which include quantified uncertainties, are merely more realistic representations of this basic aleatory model. All attempts to quantify uncertainties require expert judgment, whether it be a single expert or a panel of experts. Further, all uncertainty assessments should consider the range of views of the larger informed technical community at the time the hazard analysis is conducted. In some cases, especially for large projects under

regulatory review, formal structured methods for eliciting expert judgments have been employed. Experience has shown that certain key elements are required for these assessments to be successful, including: 1) experts should be trained in probability theory, uncertainty quantification, and ways to avoid common cognitive biases; 2) comprehensive and user-friendly databases should be provided to the experts; 3) experts should be required to evaluate all potentially credible hypotheses; 4) workshops and other interactions among the experts and proponents of published viewpoints should be encouraged; 5) elicitations are best conducted in individual interview sessions; 6) feedback should be provided to the experts to give them insight into the significance of alternative assessments to the hazard results; and 7) complete documentation should include the technical basis for all assessments. Case histories will be given from hazard analyses in Europe, western North America, and the stable continental region of the United States.

### THE STABILITY OF THE PROPORTIONAL HAZARD MODEL WITH RESPECT TO THE INPUT ELEMENTS – ID 1976

*L. Faenza, University of Potsdam, Germany*
*W. Marzocchi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*C. Meletti, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

In 2003 a new building code for Italy has been released. Subsequently a new seismic hazard reference map of Italy (MPS04) have been compiled for definition of seismic zones. In order to define priority area for any short-term policy in loss reduction in Italy, different approach have been followed and compared. One of this approach is based on the clustered feature of the earthquake occurrence for events greater than M5.5, according to the Proportional Hazard Model proposed by Faenza et al., 2003. The analysis of the distribution of large events is composed by several ingredients. In fact, besides the statistical distribution of events, the catalogue and the zonation play an important role. In this work the same input data used for the MPS04 have been introduced in the model, in order to investigate its sensitivity and the stability of the results and to check the influence into the probability distribution of factors like the zonation, the catalogue and the magnitude-temporal windows of completeness. The same non-parametric spatio-temporal model of earthquake occurrence has been applied to two different seismogenic zonations, and to two seismic catalogues; several geological-tectonic parameters for the single zones have been determined, as well as different magnitude-temporal windows of completeness have been used for the catalogues. The results show the same pattern for earthquake occurrence in all the applications, indicating a cluster properties for earthquake generation mechanism. It seams also that the cluster characteristic, in terms of time duration and intensity, may change adopting a different catalogue, but it is not influenced by the two zonations. Finally, we translate these results in term of conditional probability of occurrence in the next 10 years.

## SC-E 2-I: Deterministic and Probabilistic Prediction Methods: Theory, Applications and Case Studies

Wednesday 13:30 - 15:00 – Room 18

### EARTHQUAKE INTERACTION AND TIME-DEPENDENT SEISMIC HAZARD: A SUMATRAN CASE STUDY – ID 1944

*S. Steacy, University of Ulster, Ireland*
*J. McCloskey, University of Ulster, Ireland*
*S. Nalbant, University of Ulster, Ireland*

Immediately following the great Sumatra-Andaman earthquake of December 2004, we calculated the static Coulomb stress increases induced by it on nearby seismogenic structures. In a paper submitted on 9 January 2005, we pointed out the increased risk of an M=7-7.5 event on the Sumatra Fault and an 8-8.5 earthquake on the Sunda Trench. On 28 March 2005, 11 days after the paper was published, the Sunda megathrust ruptured again, producing a second great (M8.7) earthquake. The rupture was contiguous with that of the December 2004 Sumatra-Andaman earthquake, and its occurrence is entirely consistent with stress triggering albeit at very low stresses on the order of just 0.1 bar. The successful identification of the location and approximate magnitude of a future earthquake illustrates the potential of Coulomb stress modeling to contribute to the estimation of time-dependent seismic hazard. It's important to note, however, we were unable to say anything about the timing of the likely event.

The stresses imposed by the second rupture have now brought the megathrust immediately to the south, under the Batu and Mentawai islands, closer to failure and have expanded the area of increased stress on the Sumatran fault. Paleoseismologic studies show that the Mentawai segment of the Sunda megathrust is well advanced in its seismic cycle and is therefore a good candidate for triggered failure. The area under Siberut Island has not failed since 1797 although it has produced several intermediate size (M6-7) earthquakes in the past year and probably poses the greatest present threat. Aseismic slip under the Batu Islands, afterslip of the 2005 earthquake, and viscoelastic relaxation, increase stress on this segment and increase the hazard.

### SENSITIVITY OF SEISMIC HAZARD RESULTS TO THE TYPE OF MAGNITUDE-RECURRENCE RELATIONSHIP – ID 1324

*N. Yilmaz Ozturk, Ministry of Public Works and Settlement, Turkey*
*M. S. Yucemen, Middle East Technical University, Turkey*

In the classical probabilistic seismic hazard analysis model earthquake magnitudes are assumed to exhibit an exponential distribution. However, it is observed that the exponentially distributed magnitude model may underestimate the recurrence rate of large magnitude earthquakes on individual fault segments. Accordingly, various investigations have been carried out to develop alternative models for earthquake magnitude distribution. Among them, the so called characteristic earthquake model, which was proposed by Schwartz and Coppersmith (1984) and later modified by Youngs and Coppersmith (1985), has become the most widely accepted one. In this model, low and moderate magnitudes are assumed to be exponentially distributed and large magnitude characteristic earthquakes are considered to be uniformly distributed over a specified range. In order to apply this model to cases where there is no sufficient data to assess the parameters of the characteristic magnitude part of the model, Youngs and Coppersmith (1985) made some simplifying assumptions. The width of the characteristic magnitude part is set equal to 0.5 magnitude units and no gap is left between the exponential and characteristic magnitudes. In addition, the frequency of the characteristic earthquakes is taken equal to the frequency of the exponential magnitude at 1.5 magnitude unit less than the maximum magnitude. It is also possible to adopt different distributions for the characteristic earthquake magnitudes, like the truncated Gaussian distribution.

A case study is performed to evaluate the sensitivity of seismic hazard results to the different magnitude recurrence models that are listed above.

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### SEISMIC HAZARD MAP FOR NORTH AFRICA – ID 1642

*A. Kijko, Council for Geoscience, South Africa*
*M. Bejaichund, Council for Geoscience, South Africa*
*E. Hattingh, Council for Geoscience, South Africa*

*A. Zaghw, Cairo University, Egypt*
*R. Roberts, Uppsala University, Sweden*
*B. Lund, Uppsala University, Sweden*
*L. Hagos, Uppsala University, Sweden*

The "Parametric-Historic" procedure of Kijko & Graham (1998, 1999) was used to produce a probabilistic seismic hazard map for Northern Africa. The map depicts a 10 % probability of exceeding the calculated PGA at least once in 50 years. Seismic data for North Africa was collected from NEIC and ISC. Various historical sources from the Middle East (Samir and Tealeb (2004)), Egypt (Badawy (2005)), Ethiopia (Gouin (1979)) and Syria (Sbeinati et al., 2005) were used to gather historical data. In some seismic active areas one can expect a PGA of 0.5 g. High levels of hazard (up to 0.7 g) occur along continental edges and the East African rift system. The Parametric- Historic Approach has been applied for many areas of the Global Seismic Hazard Map (Giardini et al., 1999). A similar map was also produced using the classical Cornell (1968) procedure. The two maps are compared showing weak and strong points of both procedures. This project is funded by The National Research Foundation (NRF) in collaboration with the Swedish Research Council (SRC) and the Swedish International Developmental Agency (SIDA) to encourage research co-operation between researchers in the Middle East and North African countries.

## EARTHQUAKE PREDICTION RESEARCH AND THE JUNE 2000 EARTHQUAKES IN ICELAND – ID 1812

*R. Stefánsson, University of Akureyri, Iceland*

In June 2000 two earthquakes with magnitude 6.6 (Ms) occurred in the central part of the South Iceland seismic zone (SISZ). Earthquakes in this region have, according to historical information, in some cases caused collapse of the majority of houses in areas encompassing 1000 km2 in this relatively densely populated farming region.

Because large earthquakes were expected to occur soon much attention was given to preparedness in the region and for the last two decades it has been the subject of multinational, mainly European, cooperation in earthquake prediction research and in the development of a high level microearthquake system, the SIL system.

Despite intensive surface fissuring caused by the earthquakes and measured accelerations reaching 0.8 g, the earthquakes in 2000 caused no serious injuries and no structural collapse. The relatively minor destruction led to some optimism regarding the safety of living in the area. But it also lead to some optimism about the significance of earthquake prediction research. Both earthquakes had a long term prediction (Stefansson et al 1993) and the second of the two earthquakes had a short term warning about place size and immediacy. In this presentation I will describe the warnings that were given ahead of the earthquakes and also to reconsider them in light of new evidence from multinational earthquake prediction research in Iceland. But this evidence also points forward to even better results in providing useful warnings ahead of earthquakes in the future, based on more observations, new emerging modeling of earthquake processes and an early information and warning system, which is in development parallel to ongoing earthquake prediction research.

## SEISMIC HAZARD ASSESSMENT OF NW HIMALAYAN FOLD-AND-THRUST BELT, PAKISTAN USING A DETERMINISTIC APPROACH – ID 1611

*L. Mona, Quaid-i-Azam University, Pakistan*
*A. A. Khwaja, Quaid-i-Azam University, Pakistan*

Seismic Hazard Assessment (SHA) of the entire seismically active NW Himalayan Fold and Thrust Belt that incorporates deterministic approach has been carried out for the first time. Additional information in the form of earthquake catalogue, delineation of 40 active faults in a structural map, their relationship to the seismicity, focal mechanism studies of 45 events, establishment of seismotectonic zones has also been undertaken. Considering a number of geological and seismological factors, four seismotectonic zones have been established. The b value for the Peshawar-Hazara Seismic Zone (PHSZ) is 1.16 followed by 1.12 for the Surghar-Kurram Seismic Zone (SKSZ). The other two, Swat-Astor Seismic Zone (SASZ) and Kohat-Potwar-Salt Range (KPSZ) have identical values of 0.95 thereby indicating occurrence of more events of relatively higher magnitude as compared to the other two seismic zones. Mean activity rate of earthquakes ($\lambda$) ranges from 4.26 to 1.73. In decreasing order the values are 4.26, 2.62, 2.07 and 1.73 for PHSZ, SASZ, KPSZ and SKSZ respectively. Using 4 regression relationships, the maximum potential magnitude (m1) has been determined for the 40 Quaternary faults. In each seismic zone the highest value within the seismic zone represents its m1. Results show that m1 is 7.8 in the hinterland (SASZ and PHSZ) and 7.4 in the foreland part (KPSZ and SKSZ). SHA incorporating deterministic approach has been undertaken at 10 sites (Astore, Bannu, Kaghan, Kohat, Mangla, Malakand, Muzaffarabad, Peshawar, Talagang and Islamabad). Pakistan does not have an attenuation equation of its own. The two equations of Ambraseys et al., (1996) and Boore et al., (1997) have been used and the results obtained using the equation of Boore et al (1997) have been preferred. PGA's estimated applying Deterministic Seismic Hazard Assessment (DSHA) shows higher values for Muzaffarabad (0.79g), Islamabad (0.75g), Kohat (0.75g) and Peshawar (0.64g).

## THE PREDICTION MODEL OF PURCARU FOR LARGE IN-SLAB INTERMEDIATE-DEPTH EARTHQUAKES IN ROMANIA, AND THE OCCURRENCE OF THE NEXT LARGE VRANCEA EARTHQUAKE – ID 2079

*G. Purcaru, Univ. of Frankfurt, Institute of Meteoroly & G, Germany*

All large in-slab intermediate-depth Romanian earthquakes (EQs) occur in the Vrancea intraplate region at depth 60-175 km. Large shallow (at interface and in slab) EQs, M> 6.5, are not known. Prediction of EQs is complex and very difficult. It requires a law, deterministic or probabilistic, based on sufficient evidence in order the law be as much as possible stable and applicable. Along this view, Purcaru (1974) first found a set of empirical laws for the prediction of large Vrancea events, about M>6.7 and M>7.2. We first identified new large events (before 1475), and quantified all EQs in terms of magnitude for the period 1100-1974 (Purcaru, 1979, for catalog, etc.). Long-term prediction laws are: law of quasicycles (QCs) for M>6.7, and of supercycles (SCs) for M>7.2. The cycles found in each of three time periods, (TPs) are: (0-10, 30-40 and 70-90 yrs) in each century, although some deviations exist. The mean repeat times, RT, in the (TPs) vary from 96 to 104yr for (QCs), and about 300 yr for (SCs). The laws are essentially deterministic; due to fluctuations from the mean RT any prediction must be interval valued. We found that without the long observation period of about 1000yr and magnitude quantification of EQs no convincing laws can be evidenced. The (QC)-law for the third (TP) successfully predicted the 1977 event, M=7.1-7.2. However the time clustered large EQs in 1986 and 1990 were not predicted separately. Our model predicts the next large EQ during (TP)= 2000-2010, centered at 2005. The Purcaru's model is independent of spatial distribution of EQs; no rupture zones available at that time. Since the complex 1940 EQ, H= 122Km, M7.4, Mw7.8, ruptured down-dip possibly to 150km (Gutenberg-Richter depth). Thus the remaining depth zone 150-175km is a candidate place of the next large event, as proposed by Purcaru and Berckhemer (1998). Stronger independent sufficient evidence is, however, necessary.

## SC-E 2-II: Deterministic and Probabilistic Prediction Methods: Theory, Applications and Case Studies

Wednesday 15:30 - 16:30 – Room 18

### WHERE AND WHEN WILL THE NEXT M7 VRANCEA (ROMANIA) INTERMEDIATE-DEPTH EARTHQUAKE OCCUR? – ID 1734

*N. Hurukawa, IISEE, Building Research Institute, Japan*
*M. Popa, National Institute for Earth Physics, Romania*
*M. Radulian, National Institute for Earth Physics, Romania*

An M7 intermediate-depth earthquake occurs in the Vrancea region of Romania on average every 20 to 30 years. The last major earthquake occurred in 1986 (Mw7.2). According to the average rate frequency, a next large earthquake is expected to occur soon. Although a long-term prediction based on regularity of earthquake occurrences has already been carried out by Purcaru (1974) and Enescu et al. (1974), and the predicted M7 earthquake actually occurred in 1977, this prediction was not based on the seismic gap theory and the hypocenter could not have been precisely predicted. Here we show (i) that combining ISS/ISC global and NIEP's local network data, we can relocate earthquakes from 1934 to 2003 accurately by using the modified joint hypocenter determination method developed by Hurukawa & Imoto (1992), (ii) that the 1940 (M7.7), 1977 (Mw7.5), 1986 (Mw7.2) and 1990 (Mw6.9) major earthquakes were located inside the seismic region defined by the recent seismicity and their focal depths are 124, 101, 136 and 85 km, respectively, and (iii) that these earthquakes had, therefore, occurred at a depth range of 60-140 km with no overlapping of the aftershock areas, and the area at 140-160 km depth remains unbroken. Purcaru (1974, 1979), Enescu et al. (1974) and Enescu & Enescu (1996, 1999) predicted from the regularity of earthquake occurrence that the next major Vrancea earthquake will occur in this decade. Considering the result of this study and the periodicity of the seismic activity over the past 1000 years, the probability of the next M7 earthquake to occur in the depth interval of 140-160 km at the beginning of this century is very high.

### EVENT STUDY OF MICROWAVE EMISSION PHENOMENA ASSOCIATED WITH EARTHQUAKES – ID 1566

*M. Takashi, The University of Tokyo, Japan*
*T. Tadashi, ISAS, JAXA, Japan*

It was experimentally shown that rock crash by static pressure caused radio wave emissions at 300MHz, 2GHz and 22GHz. This result suggests that this microwave is emitted in the result of earthquakes.

Encouraged by this circumstance, we aim to establish the computer system to detect microwave emissions associated with crustal alterations, which trigger earthquakes, by a microwave radiometer loaded on a satellite. At present, the microwave radiometer 'AMSR-E' loaded on the remote sensing satellite 'Aqua' is the most suitable for our purpose. AMSR-E is a multi-frequency, dual-polarized microwave radiometer that detects faint microwave emissions from the Earth's surface and atmosphere as brightness temperature.

Considering the microwave propagation from the ground, we are now investigating the AMSR-E data on earthquakes with bigger magnitude and shallower hypocenter under the ground. On the earthquake caused by an active fault, brightness temperature is investigated both at the epicenter and at fault planes appearing on the ground. However, after investigation, it is indicated that brightness temperature fluctuates very much due to various factors.

The elimination of effects of these factors is essential to the anomaly detection of brightness temperature associated with earthquakes. Since Aqua is on a sun-synchronous orbit, by analyzing only the data in the descending track, the effect of reflection of sunlight at the Earth's surface on brightness temperature can be ignored. Moreover, on each observation, we regard the brightness temperature at the place near the special one (e.g. an epicenter) as a standard and calculate the difference of brightness temperature at each place. Therefore, by this method, the effect of seasons and climates on brightness temperature can be reduced.

As a result, right before and after some earthquakes, it has been detected that the microwave was emitted more strongly at fault planes appearing on the ground than at their vicinity.

### SHARP AN A-Z SOFTWARE TOOL FOR SEISMIC HAZARD ASSESSMENT – ID 1644

*M. Bejaichund, Council for Geoscience, South Africa*
*A. Kijko, Council for Geoscience, South Africa*

SHARP Seismic Hazard And Risk Assessment Program is a seismic hazard and risk assessment tool originally written in MATLAB and now easily deployed executable files with user-friendly graphical interfaces. A comprehensive user-manual is also available. The 4 modules of SHARP consist of:

• MODULE 1: A tool for the generation of synthetic seismic event catalogues

o MODULE 2: A tool for seismic hazard assessment at the area of interest. The application of the procedure results in the estimation of mean values of the basic seismic hazard parameters for a given area, i.e. maximum regional magnitude; mmax, mean seismic activity rate; $\lambda$, and b value in the frequency magnitude Gutenberg Richter distribution. These parameters are used further for plots of the mean return periods and respective probabilities of exceedance of specified value of magnitude

• : MODULE 3: Software for detailed assessment of the maximum regional earthquake magnitude mmax. The code is capable to assess the value of mmax according to 12 different procedures.

• MODULE 4: Application of this procedure results in the estimation of parameters describing the seismic hazard for a given site. These parameters are used further for plots of the mean return periods and respective probabilities of exceedance of specified value of PGA.

What makes this methodology for seismic hazard assessment different is: • It is free from having to specify seismic source zones, which is often very subjective • It has the ability to combine a deterministic component by adding geological and neotectonic information specific to an area • It has the ability to combine prehistoric (highly incomplete and uncertain), historic (incomplete) and instrumental (complete) earthquake data. • Seismic hazard maps can be produced • It can be applied to areas of both low and high seismicity. • There is an intensive treatment of uncertainty in the results

### CN EARTHQUAKE PREDICTION FOR THE ADRIA REGION AND ITS SURROUNDINGS – ID 1948

*A. Peresan, Department of Earth Sciences, University of Triest, Italy*
*I. Rotwain, IIEPT. Russian Academy of Sciences, Russian Federation*
*D. Herak, Department of Geophysics, University of Zagreb, Croatia (Local Name: Hrvatska)*
*G. F. Panza, University of Trieste & ICTP, Italy*

An overview of the application of the intermediate-term middle-range earthquake prediction algorithm CN for the analysis of seismicity in the Adria region and surrounding countries, namely Italy and Croatia, is provided. A regionalization, strictly based on the seismotectonic zoning, is proposed for the application of CN algorithm to the foreland areas along the Adriatic sea as well. The regionalization currently used for the routine monitoring of earthquakes occurrence in the Italian territory, which is composed by three regions located along the north-western boundaries of the Adria plate, has been defined strictly following the seismotectonic zoning and taking into account the main geodynamic features of the area. Specifically, the borders of each region have been traced including only adjacent zones with similar seismogenic behaviour and the transitional zones connected to them, compatibly with the cinematic model. Based on the successful results obtained so far (including the real-time prediction test for earthquakes with magnitude larger than 5.4 in the monitored territory), a region

suitable for CN application to the Adriatic sea is defined, following the same rules controlling the definition of the three regions in the Italian territory. The new area, the Adria region, is composed by the foreland areas extending from the Adriatic Sea to Southern Sicily, trough the Ionian Sea. A number of stability tests, taking into account different configurations of the area of investigation and different choices of the free parameters of the algorithm, are satisfactorily performed. The obtained results seem to support the hypothesis, that precursors can be found inside seismogenically homogeneous areas associated to a dominating geodynamic process. Hence the seismotectonic model may represent an useful guide in the selection of the fault systems involved in the preparation of strong earthquakes.

## SC-E 3 & SC-F 2-I: Time-Dependant Earthquake Hazard Assessment

Tuesday 10:45 - 12:15 – Room 18

### STATIC STRESS CHANGES ASSOCIATED WITH THE OCCURRENCE OF STRONG EARTHQUAKES IN BULGARIA AND NORTHERN GREECE – ID 1592

*E. Papadimitriou, Aristotle University of Thessaloniki, Geophysics D, Greece*
*V. Karakostas, Aristotle University of Thessaloniki, Geophysics D, Greece*
*M. Tranos, Aristotle University of Thessaloniki, Geology D, Greece*
*B. Ranguelov, Geophysical Institute, Bulgarian Academy of Scienc, Bulgaria*
*D. Gospodinov, Geophysical Institute, Bulgarian Academy of Scienc, Bulgaria*

Activation of major faults in Bulgaria and northern Greece presents significant seismic hazard because of their proximity to populated centers. The long recurrence intervals, of the order of several hundred years as suggested by previous investigations, imply that the 20th century activation along the southern boundary of the Sub–Balkan graben system, is probably associated with stress transfer among neighbouring faults or fault segments. Fault interaction is investigated through elastic stress transfer among strong main shocks (M>6.0), and in three cases their foreshocks, which ruptured distinct or adjacent normal fault segments. We compute stress perturbations caused by earthquake dislocations in a homogeneous half–space. The stress change calculations were performed for faults of strike, dip, and rake appropriate to the strong events. We explore the interaction between normal faults in the study area by resolving changes of Coulomb failure function since 1904 and hence the evolution of the stress field in the area during the last 100 years. Coulomb stress changes were calculated assuming that earthquakes can be modeled as static dislocations in an elastic half–space, and taking into account both the coseismic slip in strong earthquakes and the slow tectonic stress buildup associated with major fault segments. We evaluate if these stress changes brought a given strong earthquake closer to, or sent it farther from, failure. The modeling results show that the generation of each strong event enhanced the Coulomb stress on along–strike neighbors and reduced the stress on parallel normal faults in the study area. We extend the stress calculations up to present and provide an assessment for future seismic hazard by identifying the fault segments that are possible sites of future strong earthquakes.

### APPLICATION OF PATTERN INFORMATICS METHOD TO FORECASTING THE LOCATIONS OF FUTURE LARGE EARTHQUAKES IN THE CENTRAL JAPAN – ID 1760

*K. Z. Nanjo, The Institute of Statistical Mathematics, Japan*
*J. R. Holliday, University of California at Davis, United States*
*C. C. Chen, National Central University, Taiwan*
*J. B. Rundle, University of California at Davis, United States*
*D. L. Turcotte, University of California at Davis, United States*

Time-dependent earthquake hazard assessment is often associated with probability-based forecasting of future seismicity. This forecasting is to evaluate the times, locations, and magnitudes of future earthquakes, using the concept of probability. Here we concentrate our attention on the "locations" and present an applicable statistical-physics-based method. Our method is called Pattern Informatics (PI), which can detect the locations of temporal change in seismicity (seismic activation and quiescence) associated with the occurrence of future earthquakes. The output is a hazard map of areas with probabilities that large earthquakes are likely to occur in a future 10-year span. Applications of PI method to California and on a worldwide basis have also forecasted the location of future earthquakes. In this presentation, we show its application to the central part of Japan. We discuss our results from several geophysical viewpoints and indicate that the PI method shows considerable promise as an intermediate-term earthquake forecasting tool for the central Japan. It is of interest to extend the PI method so as to be applicable for forecasting the times and magnitudes of future earthquakes.

### COULOMB STRESS, EARTHQUAKE PROBABILITIES, AND SEISMIC RATES – ID 1939

*S. Steacy, University of Ulster, Ireland*
*J. McCloskey, University of Ulster, Ireland*

It is now widely accepted that Coulomb stress perturbations affect the location and timing of subsequent events and hence have clear implications for time-dependent hazard. Quantifying the hazard change is not straight forward, however, due to the extreme non-linearity of the earthquake process. One of the more promising approaches is based on a rate-state friction model in which the increase in seismic rate due to a sudden stress step can be estimated. Crucially, however, this rate increase depends on the background seismicity rate so that regions with greater background rates undergo greater rate (and hence probability) changes.

Can a meaningful background seismicity rate be measured? We test this in the southern California catalog which, from inspection of the frequency size distribution, is relatively complete for M>3.0 and contains >15000 events from 1932 to present. In the region covered by the entire catalog, we find that regional seismic rate does not converge over timescales of tens of years. As Coulomb stresses affect relatively small areas, however, the practical issue may be whether a stable background rate can be measured at small temporal and spatial scales; we are now investigating this systematically.

### STEP, EEPAS AND THE NEW ZEALAND EARTHQUAKE FORECAST TESTING CENTRE – ID 1920

*M. Gerstenberger, GNS Science, New Zealand*
*D. Rhoades, GNS Science, New Zealand*

Time-dependent hazard is more and more becoming a focus of earthquake hazard research. There are many approaches to time dependence, with model forecasts ranging from one day to decades. Here I present a centre dedicated to developing and testing forecasting models for New Zealand, and will also discuss the details of two models to be implemented within the centre: STEP and EEPAS. STEP provides forecasts of the probability of experiencing Modified Mercalli Intensity VI in the next 24 hours. The methodology is based on aftershocks, but includes the long-term contribution from standard hazard maps (e.g., the United States Geological Survey (USGS) and N.Z. National Hazard maps). Following review by the California Earthquake Prediction Evaluation Council, the USGS has issued the STEP forecasts for California online and made them available to the public since May 2005. The EEPAS model is based on the idea that every earthquake is a long-term precursor and will therefore give rise to a temporary magnitude-dependent increase in the rate of earthquake occurrence; the duration of the rate increase is on the order of a year at magnitude 5 and up to several decades at magnitude 8. When combined, the models cover a broad spectrum of time dependence and can potentially provide better information than

either individual model. An understanding of how effective a combined model is will come through testing of the models via the New Zealand centre and RELM, a California-based testing centre. The New Zealand centre is based on the ideas of RELM, which provides a rule-set for how models should be tested and requires registration of models and forecasts within the centre. Such centres have an important role to play in encouraging the development of improved forecasting methods by providing transparent and community-accepted tests of model performance.

### IMPACT OF TIME-DEPENDENT EARTHQUAKE OCCURRENCE ON PROBABILISTIC SEISMIC HAZARD ANALYSIS IN LOW SEISMICITY AREAS. – ID 1708

*L. Faenza, University of Potsdam, Germany*
*S. Hainzl, University of Potsdam, Germany*
*F. Scherbaum, University of Potsdam, Germany*

Standard seismic hazard analysis assumes constant temporal earthquake occurrence probabilities even though there is clear evidence that earthquakes are not random in time. Most known in this context are aftershock sequences following crustal earthquakes. The goal of this work is to quantify the impact of non-Possonian earthquake occurrence on Probabilistic Seismic Hazard Analysis (PSHA) on different time scales. For this purpose we perform a non-parametric analysis of the spatio-temporal distribution of earthquakes for selected intraplate test regions. In addition, we study extreme cases of firstly cycling mainshock occurrence and secondly aftershock activity following a recent mainshock. Once the spatio-temporal behaviour is selected, a validation test is performed on observed data to guarantee that the model is a good representation of the observations. Subsequently, we quantify the effect of the spatio-temporal distribution on hazard estimates, in particular, the impact against the null hypothesis of Poinssonian behaviour of seismicity. In this way, we estimate the most likely as well as the maximum possible impact of time-dependent earthquake occurrence for hazard estimations on different time intervals.

## SC-E 3 & SC-F 2-II: Time-Dependant Earthquake Hazard Assessment

Tuesday 13:30 - 15:00 – Room 18

### SEISMIC HAZARD OF THE NORTH-SOUTH SEISMIC ZONE, CHINA – ID 582

*S. Cole, University of East Anglia, UK*
*Y. Xu, University of East Anglia, UK*
*P. Burton, University of East Anglia, UK*

The North-South Seismic Zone (NSSZ) is the most seismically active area of China. It is a shear zone, in midwest China, resulting from the extension of the Tibetan plateau to the west and the resisting forces of the Sichuan basin and Ordos block to the east. Devastating earthquakes within the last two centuries have resulted in large losses of life and damage within this zone. Examples include: 1920 8.4Ms Haiyuan, 1927 7.7Ms Gulang and 1833 8.0Ms Songming. A seismogenic free zone analysis of the NSSZ is presented. The NSSZ is divided into two sections based on spatial seismicity and tectonics. The extreme distributions of Gumbel are applied to determine the upper bound magnitude, peak ground acceleration and maximum intensity for the next 50, 100 and 200 years together with the 90% probability of non exceedance in the next 50 years. Cumulative strain energy release is shown graphically for varying time intervals and subsections of the zone to find the maximum credible magnitude, M3, and the waiting and delay times for M3, assuming no other earthquakes occur meantime. These results show that the highest hazard is located within close proximity to known tectonic faults. To the south of the NSSZ the Xianshuihe, Anninghe-Zemuhe and Xiaojiang left-lateral faults represent the eastern edge of the Sichuan-Yunnan block which is escaping southeastward from the Tibetan plateau. The north is a combination of strike-slip and thrust faults as the Tibetan plateau, resisted by movement to the north, extends northeast. Contacts: s.cole@uea.ac.uk

### BRICK BY BRICK - THE NEXT STEPS IN EARTHQUAKE PREDICTION RESEARCH – ID 1945

*D. Schorlemmer, ETH Zurich, Switzerland*
*T. H. Jordan, University of Southern California, United States*
*M. Gerstenberger, Institute of Geological & Nuclear Sciences, New Zealand*
*S. Wiemer, ETH Zurich, Switzerland*
*P. Maechling, University of Southern California, United States*

After a period of searching for the silver bullet of earthquake prediction, i.e. a generic precursor, the scientific community is starting to broaden their perspective on new approaches. New efforts, namely RELM (Regional Earthquake Likelihood Models) and CSEP (Collaboratory for the Study of Earthquake Predictability), recollect the stepwise, "brick by brick", approach in earthquake prediction research, recognizing it as a social demand and a scientific challenge. Three questions need to be addressed: (1) How should scientific earthquake predictions be stated and tested? (2) What is the intrinsic predictability of the earthquake rupture process? (3) Can knowledge of large-earthquake predictability be deployed as useful predictions? CSEP will focus on experimentation (Question 1) and predictability (Question 2), not operational prediction (Question 3).

CSEP will establish a controlled environment for the rigorous registration and evaluation of earthquake predictability experiments and conduct prediction experiments to gain a physical understanding of earthquake predictability on time scales relevant to seismic hazards. CSEP will become a global effort by including local research and testing facilities in California, Europe, New Zealand, and Japan.

### MODEL-FREE ESTIMATION OF MAGNITUDE DISTRIBUTION AS A TOOL ROBUST TO DEPENDENCIES OF THE EARTHQUAKE SERIES FROM A TIME-VARYING GENERATING PROCESS – ID 1938

*S. Lasocki, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*
*E. Papadimitriou, University of Thessaloniki, Greece*

A time-varying earthquake process results in the seismic series, which are not simple statistical samples. Consequently, a non-standard approach to estimating of the probability distribution functions of source parameters in needed. Interesting flexible solutions to this problems are offered by kernel estimation methods. These methods are model-free thence they provide estimators that depend solely on the data. We exemplify a power of the kernel estimation presenting the results of its application to the analysis of earthquake return periods. The studies were performed on both the original and the declustered catalog of events from a seismotectonically homogeneous region of Greece. In both the cases the model-free estimates of recurrence intervals of larger earthquakes, obtained from a relatively short period of observations agreed well with long-term occurrences of such events.

### CONDITIONAL EARTHQUAKE PROBABILITIES OVER PERIODS FROM DAYS TO DECADES – ID 1810

*A. Christophersen, New Zealand*
*E. G. C. Smith, Victoria University of Wellington, New Zealand*

A combination of Omori's law for aftershock decay and a Poisson distribution describes well the inter-event-times between successive earthquakes in a region. The model has only two effective parameters: The weight between the two model components and the Poisson time constant. Two further parameters assure that Omori's law has no singularities at zero and infinity; but the model is insensitive to them.

We used the global catalogue of the International Seismological

Centre and defined 79 superclusters consisting of all earthquakes larger than magnitude 6.5 between 1985 and 2000 in a region centered on the largest earthquake within a radius of 144 km and 455 km for magnitude 7.0 and 8.0 respectively. We fitted a total of 341 inter-event-times by maximum likelihood. We then applied the model to a single supercluster of 15 earthquakes with M <= 7 that occurred in central New Zealand since 1840. Comparison with the global model suggests that a small number of large aftershocks may be missing from the New Zealand catalogue.

As a general result, if more than about 100 days pass following a large earthquake without a second one as large, the probability of a subsequent earthquake is approximately the same as given by a Poisson model. As the elapsed time increases the probability falls. This general behaviour is consistent with the seismic gap hypothesis.

We found the 1/t form of Omori's law to be universal. Others' reported observations of p > 1 in the modified Omori law can be explained by our model or by statistical insignificance.

The result that the best fit for the second part of the model is an exponential implies that 'new' or background earthquakes are truly independent, and therefore cannot be modeled by either time or slip predictable models.

### ELASTIC AND INELASTIC STRESS TRIGGERING IN THE SOUTH ICELAND SEISMIC ZONE DUE TO LARGE EARTHQUAKES SINCE 1706 – ID 1870

*S. M. Richwalski, CEDIM / GeoForschungsZentrum, Germany*
*F. Roth, GeoForschungsZentrum (GFZ), Germany*

Damaging earthquakes in the South Iceland Seismic Zone (SISZ) occur fairly regularly and often as a series of events with a few days only between individual events. Tolerably reliable information on epicentre locations and mechanisms are available for 13 M $\geq$ 6 events between 1706 and 2000. For these events, we computed the co- and post-seismic stress fields, hereby approximating the SISZ by a mixed elastic/inelastic layered half-space. The horizontal shear stress and the Coulomb stress changes were analysed to detect possible trigger mechanisms, which may aid future earthquake mitigation efforts. We tested several criteria but must conclude that the start of an earthquake series in the SISZ cannot be explained by triggering through previous events. Inside an individual series, however, one may infer triggering. Our results are in contradiction with findings in other regions of the world. The reason might be related to the fact that the SISZ is not a mature fault zone, in which old faults are re-activated if a certain stress level threshold is passed. In addition, uncertainties in the model parameters as well as the neglect of horizontal variations in the model and of possible stress transfer due to volcanic activity further complicate the evaluation of our results and need to be taken into account in future studies.

### INVESTIGATING SEISMICITY RATE CHANGES DURING THE JUNE 2000 SEISMIC DOUBLET IN ICELAND – ID 1861

*G. Daniel, LGIT, France*
*D. Marsan, LGIT, France*
*M. Bouchon, LGIT, France*

We present an analysis of seismicity rate changes that occurred during the June 2000 seismic doublet in Iceland. Particularly, we are interested in characterizing the impact of the second M6.5 mainshock (occurring on June, 21st 2000) on the preexisting seismicity (mainly aftershocks of the June, 17th M6.5 earthquake). Both spatial and temporal aspects of this perturbation are investigated. On one hand, off-faults areas appear to have experienced triggering of seismicity to the west of the June, 21st fault plane; though the areas to the east of the fault plane exhibit very significant quiescence of activity. This decrease of seismicity rate is temporally correlated with the occurrence of that last event. On the other hand, as fault planes related with both events are only 17 km appart, we will present how seismicity linked with the June, 17th fault plane was perturbated by the June, 21st event. These results, deduced from observations by the SIL permanent network, may reveal very useful information as regards the aftershock generation process. Thus, such results may be of great interest for seismic hazard estimates, as they need to include the best possible knowledge on how occurrence of strong/moderate mainshock may spatially and temporally influence the preexisting microseismcity. Finally, if one considers that the interaction process between earthquakes obeys the same behavior for large events and microactivity, this work may help in understanding which parameters put an area towards reactivation, or quiescence of seismic activity.

## SC-E 3 & SC-F 2-III: Time-Dependant Earthquake Hazard Assessment

Tuesday 15:30 - 17:00 – Room 18

### NONPARAMETRIC BAYESIAN INFERENCE IN RENEWAL RECURRENCE MODELS – ID 2007

*R. Rotondi, Consiglio Nazionale delle Ricerche - I.M.A.T.I., Italy*

Despite the large number of studies on the time-dependent hazard a commonly accepted model does not exist yet, but there are some more shared conjectures as the dependence on the time elapsed since the last occurrence, that is, the idea that after each event the probability of the future process may be the same. From the probabilistic point of view this means to consider renewal processes. They are appropriate to model large earthquakes after which one can assume that the stress accumulation process restarts. Statistically this implies that the times between large seismic events can be considered as realizations of independent, identically distributed random variables, the interoccurrence times. Various probability distributions have been considered in the literature for these times. When satisfactory results in terms of fitting were obtained, then one looked for physical interpretations of the underlying process; for instance, distributions with decreasing hazard can support the idea that there are strong interactions among neighbouring fault segments. We prefer the opposite way of dealing with the problem: we do not make any assumption on the functional form of the distribution of the interoccurrence time and strengthen the probabilistic methodology by considering such a distribution as a random function modelled by a Polya process. The approach followed for estimation is Bayesian, semi-parametric; we just assume that the prior expectation of the unknown density function is chosen in the class of the generalized gamma distributions for its extremely great flexibility. Renewal models have to be applied in intraplate regions for global hazard assessment and for decade-long forecasts.

### THE APPLICATION OF MULTIPLE RANDOM EARTHQUAKE SIMULATIONS TO PROBABILISTIC SEISMIC HAZARD ASSESSMENT IN THE AEGEAN REGION – ID 583

*G. Weatherill, University of East Anglia, UK*
*P. Burton, University of East Anglia, UK*

The Aegean region is the most seismically active area of Europe and has experienced many damaging earthquakes throughout recorded history. Overlying a complex tectonic regime, the region experiences a wide diversity of earthquake behaviour, with enormous disparity in focal mechanism and spatio-temporal distribution. Traditional methods of probabilistic seismic hazard analysis (PSHA) are not always able to accurately capture such complexity. It may be possible, however, to turn to a method that allows for uncertainty in the parameters of the frequency-magnitude distribution, maximum magnitude (Mmax) and attenuation relation. Multiple random earthquake simulations, via Monte Carlo simulation, offer the opportunity to analyse seismic hazard across the Aegean, whilst still allowing for uncertainty. They may also enable meaningful determination of hazard (in terms of Peak Ground Acceleration (PGA) and Intensity) with exceedence

probabilities significantly smaller than those currently used in standard PSHA techniques. In addition, these simulations can also be used to conduct sensitivity analyses that will act as a verification process, against which our assumptions regarding the seismic hazard parameters are continually tested. A catalogue of earthquakes in the Aegean (1900-1999AD) is used as a basis for fitting appropriate models of spatial distribution, frequency-magnitude relation and maximum-magnitude. This has been achieved by both random re-sampling of the catalogue, and by random sampling from fitted distributions, including Bounded Gutenberg-Richter and Gumbel types I and III. Simple hazard analyses for selected locations within the Aegean have been undertaken using the earthquake simulations. Using appropriate attenuation relations, PGA has been determined, and its variability quantified. The PGA with a 10% probability of exceedence in 50 years is largely consistent with those of current hazard analyses, which may give the user additional confidence in the hazard determined for lower exceedence probabilities.

### IDENTIFICATION OF TEMPORAL PATTERNS IN THE SEISMICITY OF SUMATRA USING POISSON HIDDEN MARKOV – ID 328

*K. Orfanogiannaki, of Geodynamics, National Observatory of Athens, Greece*
*D. Karlis, Athens Univercity of Economics and Business, Greece*
*G. Papadopoulos, of Geodynamics, National Observatory of Athens, Greece*

Data collected from the same area in successive time intervals tend to be dependent and thus, appropriate models for statistical modeling must accommodate this dependent structure. In PHMM each observation is generated by one of m Poisson processes, that are called states. These states are unobserved and the random mechanism that chooses which state generates each observation is, in fact, a Markov chain. The state/phase in which an area is at a given period depends on the one in the previous period, through the transition probability matrix of the Markov chain. The model incorporates a varying seismicity rate, it detects the changes on the rate over time and it correspond a different rate to each state.

On 26 December 2004 and 28 March 2005 occurred two of the largest earthquakes of the last 40 years between the Indo-Australian and the southeastern Eurasian plates with moment magnitudes Mw=9.1 and Mw= 8.6 respectively. Poisson Hidden Markov models (PHMM) are used for identifying temporal patterns in the time series of the two mainshocks. Each time series consists of earthquake counts, in different time units (days, two-day periods, five-day periods), in the regions determined by the aftershock zones of the two mainshocks. The unobserved sequences of states that underlie the time series of the two mainshocks are estimated using PHMM and similarities between them are investigated. Additionally, arguments that with some probability we expect an increase or a decrease of seismic activity in the epicentral regions of the two mainshocks for a large time frame are extracted.

### TEMPORAL DEVELOPMENT OF B-VALUE BEFORE SEPTEMBER 7TH 2004 ERUPTION AT MT. ETNA (ITALY). – ID 1825

*I. Agostino, Dept. Scienze Geologiche, Italy*
*S. La Delfa, I.R.M.A. - O.Me.G.A., Italy*
*G. Patané, Dept. Scienze Geologiche, Italy*
*G. Tringali, I.R.M.A. - O.Me.G.A., Italy*

In this work we analyzed the variations of the b coefficient in the frequency-magnitude relationship for earthquakes which occurred at Mt. Etna volcano (Sicily) from 01/01/2003 to 31/01/2006. The used earthquake data comes from the O.Me.G.A. (Environmental Meteorological and Geodynamical Observatory) of Acireale and INGV (Istituto Nazionale di Geofisica e Vulcanologia-section of Catania) datasets. The entire catalogue consist of 1475 earthquakes with ML ranging from 0.9 and 3.9, reduced to 1044 events after exclusion of those falling out of the completeness threshold (Ml$\geq$1.5). The b-values calculated using both the Maximum Likelihood and the Least Squares methods, show similar trend and in particular an increase starting from a few months before September 7th, 2004 eruption and a decrease for the following nine months. Similar trends have been noted in the 2003 period in which a recharging magma phase of the volcano occurred, as reported in literature using many other methodologies. Results obtained studying the b-value trend and the comparison with the other published data, are here in discussed. Finally, some preliminary result about the spatial b distribution are also presented.

### TOWARDS TESTING THE PRECURSORY SEISMIC QUIESCENCE HYPOTHESIS – ID 1959

*T. Van Stiphout, ETH Zurich, Switzerland*
*S. Wiemer, ETH Zurich, Switzerland*

Improving time-dependent hazard assessment will require the integration of precursory signals into a probabilistic framework. Many precursory phenomena have been observed, but few besides simple earthquake clustering have been integrated successfully into time-dependent hazard assessment. Precursory Seismic Quiescence of microearthquakes (PSQ) is one promising precursory signal type; it has been investigated in more than 100 publications in the past 25 years; nevertheless it is neither widely accepted in the seismological community nor currently usable for short or medium term hazard assessment.

To make progress in investigating the PSQ hypothesis we plan over the next three years to: (1) improve the methodology for PSQ analysis, (2) re-investigate past case studies and (3) build prospective tests for selected regions. Here, we show results of part 1 and 2.

In a first step we improve the methodology for assessing the significance of seismicity rate changes, in three ways: 1) We systematically explore the effect of declustering on seismic rate changes by using a Monte Carlo Simulation (MCS) over input parameters of different declustering algorithms as Reasenberg's, windowing techniques, or stochastic declustering. 2) To improve our understanding of the dependency of the rate change as a function of the six-dimensional parameter space (x, y, z, time, duration, and sampling area), we introduce MCS over these input parameters to test their effect on seismic quiescence. 3) We introduce a translation of rate change estimators into parameter independent probabilities, which then can be compared across different parameter spaces.

We illustrate these techniques on different documented case studies. Preliminary results show that in a few cases, the influence of Reasenberg declustering is significant and has to be considered for further studies. Gathering these results/effects allow us to build prospective tests of time-dependent hazard fluctuations due to the observation of PSQ for selected regions.

## SC-E 5: Earthquakes : To Predict or not to Predict? (Controversial Debate)

Thursday 17:15 - 18:15 – Room 2

No written contributions submitted to this session

## SC-E 6: Earthquake Physics - Field and Laboratory Study

Thursday 15:30 - 17:00 – Room 15

### ASYMMETRIC SEISMIC PULSES ARISING AND SYNCHRONIZATION BEFORE THE EARTHQUAKES – ID 329

*G. Sobolev, Institute of Physics of the EARTH RAS, Russian Federation*
*A. Lyubushin, Institute of Physics of the EARTH RAS, Russian*

*Federation*

Records obtained at the Petropavlovsk, Yuzhno-Sakhalinsk, Magadan, Yakutsk, and Obninsk IRIS broadband stations before the Kronotski (Kamchatka) and Neftegorsk (Sakhalin) earthquakes are investigated with the use of various programs of processing and analysis of time series. The initial realizations consisted of discrete measurements with a sampling rate of 20 Hz. The most attention is given to the study of microseismic variations within a minute range of periods. As distinct from other stations, the Petropavlovsk and Yuzhno-Sakhalinsk records revealed asymmetric pulses about 3-10 min long that arose several days before the Kronotski (M=7.8) and Neftegorsk (M=7.0) earthquakes. The time difference between the successive pulses decreases toward the moments of the Kronotski and the Neftegorsk earthquakes. Intervals of a stable manifestation of several periods (tens of minutes) of pulses (synchronization intervals) were found. No anomalous meteorological effects were recorded in these intervals. The asymmetric pulses arising and synchronization intervals, as well as the foreshock activation, are indicators of the unstable state of a seismically active region.

## MULTIFRACTAL MEASURES OF SYNCHRONIZATION OF MICRO-SEISMIC OSCILLATIONS BEFORE STRONG EARTHQUAKES – ID 277

*A. Lyubushin, Institute of Physics of the Earth, Russian Federation*

Report presents results of investigating synchronization effects within permanent seismic records obtained at the Petropavlovsk, Yuzhno-Sakhalinsk, Magadan, Yakutsk, and Obninsk IRIS broadband stations before the Kronotski (Kamchatka, 1997, M=7.8) and Neftegorsk (Sakhalin, 1995, M=7.0) earthquakes using estimates of singularities multi-fractal spectra evolution within moving time window. The initial data consist of measurements with a sampling rate of 20 Hz but preliminary they were averaged and down-sampled to discrete time interval 30 seconds. Thus, the investigation concerns the minute range of periods of micro-seismic oscillations. For each of the simultaneous time series the multifractal spectrums were estimated in the moving time window of the length 12 hours taken with mutual shift 1 hour using deflection fluctuation analysis. The multifractal measure of synchronization could be introduced as some measure of simultaneous variations of singularities spectra functions shapes for different signals. The report presents a number of such measures and demonstrates peak behavior of such measures before strong earthquakes for micro-seismic oscillations in minute range of periods what means the presence of precursory synchronous deterministic component.

## WHEN THE EARTH SPEAKS : UNDERSTANDING PRE-EARTHQUAKE SIGNALS – ID 426

*F. Freund, NASA ARC/SJSU, United States*

Losses due to earthquakes are assessed on the basis of probability models developed primarily from historical seismic data. However, Earth also often sends out other signals prior to major seismic events. These pre-earthquake signals are very varied. They range from ionospheric perturbations, low-frequency electromagnetic emissions, strange fluctuations of the infrared radiative flux from the land surface to many others. These signals have gotten “a bad name” in the science community. The reason is that, until now, nobody could offer a physically consistent explanation how the Earth might be able to produce such signals. Many hypotheses have been proposed but all seem to be flawed. This is a science paper. I’ll describe innovative rock deformation experiments, which demonstrate that, when igneous rocks are stressed, they generate electric currents – like a battery. The currents propagate through the rocks. They fluctuate. They cause the rock surface to become positively charged and to shine in the infrared. Key is the discovery of electronic charge carriers that normally lie dormant in the rocks but are awakened by stress. These charge carriers are defect electrons in the oxygen sublattice, known as “positive holes” or p-holes for short. The p-holes are long-distance runners. They live and travel in the valence band. They jump from grain to grain. They can cross boundaries between different types of rocks. They hold the key to decipher the many diverse signals, which the Earth sends out while stresses build up deep below to dangerously high levels. Now we can begin to listen when the Earth speaks. Soon we may be able to understand. When we reach this stage, the doors will open, inviting us to think about a worldwide earthquake early warning system.

## HYDRAULIC FRACTURING IN OIL/GAS RESERVOIRS HELPS OUR UNDERSTANDING OF EARTHQUAKE RUPTURE GENERATION – ID 1787

*T. Fischer, Geophysical Institute ASCR, Czech Republic*
*L. Eisner, Schlumberger, UK*
*S. Hainzl, Potsdam University, Germany*
*Z. Jechumtalova, Geophysical Institute ASCR, Czech Republic*

Hydraulic fracturing is often used to increase the productivity of gas/oil reservoirs that exhibit decreasing hydrocarbon pressure and permeability of oil-bearing sediments. The generated hydraulic fracture is accompanied by shear cracks, which emit acoustic energy waves that, if recorded by a vertical array of geophones, enable the resulting microseismic events to be located by seismic methods. We show the space-time distribution of several thousand microearthquakes recorded during a hydraulic treatment with the relation of injection rate to the spreading of the fracture front and to the energy of events. The hydraulic fracture elongates in one direction corresponding to the maximum compressive stress. It grows almost linearly with time until shutting down the injection pressure; later growth continues with a decreasing rate until the pressures are balanced. Focal mechanisms show a uniform strike-slip pattern with one nodal plane slightly deviating from the fracture trend. This unfavourable focal mechanism orientation may indicate high fluid pressure acting in the fracture.

## ACOUSTIC EMISSION UNDER WATER PENETRATING INTO LOADED SAMPLE : A POSSIBLE MODEL OF SWARM SEISMICITY – ID 374

*A. Ponomarev, Instiute of Physics of the Earth, Russian Federation*

The long-term experiments to study the acoustic activity regularities under biaxial compression of geological environment models of about 4000 cc composed from cement, sand and granite chips were tested under biaxial compression were carried out. The duration of experiments was run up to the first hundreds of days. We tried to establish how acoustic emission (AE) varies with water intrusion into zone of fissuring. Models were step-loaded up to approximately of 0.8 of failure load and then were held under constant load. At the intervals of fixed load water (0.5 ml) was applied on the surface and absorbed. After fluid penetration a noticeable growth of AE located in the fracture zone was noted. It is important to emphasize that unlike the earlier experiments we did not injected fluid under pressure into the loaded sample and therefore hydraulic fracturing was ruled out. The following main conclusions could be formulated from these tests: - infusion of small volume of water into cracks brings the sharp localized AE increasing, most likely due to influence of water on the surface of stressed (active) cracks; - the amplitude distribution of initiated AE signals is near to Gutenberg-Richter law; - the structure of AE after water infusion reflects two competitive processes: increasing of instability and relaxation; - different types of initiated AE time series could be described by function based on equation $de/dt = e^{\circ}\exp[(g \bullet f - U^{\circ})/kT]$ known from strength kinetic theory under the assumption that activation energy $U^{\circ}$ and effective stress f are time-dependent; - the structure of AE after water infusion is qualitatively close to the same for earthquake’s swarms and sometimes to aftershock decays. The work was supported by RFBR grant 05-05-08022.

### CHANGES IN HYDROLOGIC REGIME IN WESTERN BOHEMIA DURING THE 1985/86 EARTHQUAKE SWARM – ID 1752

*J. Malek, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*O. Novotny, Charles University, Fac. of Math. and Phys., Czech Republic*
*V. Stejskal, Institute of Rock Structure and Mechanics AS CR, Czech Republic*

The contribution deals with some hydrologic effects in the West-Bohemia/Vogtland seismoactive region. In 1957, a hydrologic borehole was drilled at a distance of 2 km from the Frantiskovy Lazne spa. Reaching a 55 m depth, the borehole exploded (a geyser of water, sand and carbon dioxide). This decompression affected the individual mineral springs in Frantiskovy Lazne, but in different ways. We consider this drilling accident to be an interesting natural experiment, valuable for understanding the earthquake phenomena. Similar changes in mineral springs in Frantiskovy Lazne, but of the opposite sign, occurred during the 1985/86 earthquake swarm. The spa was located at a distance of 15 km from the epicentral area. It follows from the similarity of the mineral springs variations in 1957 and 1985/86 that, during the swarm, carbon dioxide was probably injected into the same underground water reservoir. We thus conclude that an injection of crustal fluids probably played an important role in the earthquake swarm. Considering this mechanism, existence and reliability of hydrologic precursors of earthquakes in this region will be discussed. Hydrologic changes in other localities of the region will also be mentioned.

### THE STRUCTURE OF THE CHUYA EARTHQUAKE (2003 SEPTEMBER, M=7.3) AFTERSHOCK PROCESS BY DD-TOMOGRAPHY – ID 1225

*A. Emanov, Institute of Geophysics SB RAS, Russian Federation*
*E. Leskova, Institute of Geophysics SB RAS, Russian Federation*

The algorithms employed so far in obtaining the locations of earthquakes in the Altai-Sayan region were designed for a scarce regional seismological network. The deployment of a denser network of the Altai seismological test site made it possible to use other methods allowing more accurate solutions from local data. The methods we used to reprocess the Chuya earthquake (Gorny Altay, Russia, 27 September 2003, MS=7.3) data provided a clearer idea of the space distribution of aftershocks and of the aftershock process as a whole. In this work we have used additionally the double-difference tomography method, so-called DD-tomography. This processing technique unites opportunities of a double differences method and a seismic tomography. Using geological information about a structure of Chuya earthquake area we represent more detailed vision of process. In this work reprocessing of earthquakes location was received by DD-tomography method, velocity model was constructed for epicenter zone. Aftershoks location was compared with block-dividing fault and fracture deformations that mapped on the surface. In this activation three large events are emphasized. And also three activation structures are emphasized by DD-tomography. In addition each of these structures has a large events.

## SC-F 1-I: Approaches to Model Seismic Scenarios

Friday 10:45 - 12:15 – Room 22

### FULL SEISMOGRAM ENVELOPE INVERSION FOR THE ESTIMATE OF THE ATTENUATION PARAMETERS: INFERENCES FOR SEISMIC RISK ANALYSIS – ID 1709

*E. Del Pezzo, INGV, Italy*
*D. Galluzzo, INGV, Italy*
*M. La Rocca, INGV, Italy*
*F. Bianco, INGV, Italy*

Ground motion parameters, such as duration, deduced from seismograms, are essential for describing the characteristic of motion in a compact and quantitative form. Multiple scattering models describe the energy envelope of the seismograms in terms of three parameters: the energy at source, the intrinsic dissipation and the scattering attenuation coefficient. The pattern of the seismogram energy envelope as a function of lapse time mainly depends on the amount of scattering in the propagation medium. There are two extreme situations: one in which the earth medium is opaque (high scattering attenuation) and the opposite in which the earth medium is transparent (low scattering attenuation). In the transparent medium the amplitude decay vs time is higher than that in the opaque medium. This may be important in the simulation of the ground shacking duration for the analysis of the seismic risk. In facts, the experimental data show that there are zones (for examples volcanic areas) in which scattering predominate, and others in which intrinsic dissipation is more important than scattering attenuation. Consequently, the experimental knowledge of the relative amount of intrinsic dissipation and scattering attenuation is important in order to correctly address all the physical features related to the ground motion processes. These results should be taken into account for waveform simulation because ground motion duration has strong influence on earthquake damage.

### TWO VALIDATIONS OF A KINEMATIC APPROACH TO CALCULATE SEISMIC HAZARD SCENARIOS – ID 387

*F. Pettenati, Istituto Nazionale O.G.S., Italy*
*L. Sirovich, Istituto Nazionale O.G.S., Italy*

Recently, we validated the intensity-based source inversions of two earthquakes with our new "KF" technique: the ML5.9 Whittier Narrows, 1987 earthquake in the Greater Los Angeles Region (B.S.S.A., 93, pp. 47-60; B.S.S.A., 94, pp. 1737-1747), and the M5.8-6.2 Cansiglio, 1936 earthquake in NE Italy (J.G.R., 109, 2003JB002919, 2004). In the present paper, we use our kinematic "KF" approach in the direct mode to produce two seismic hazard scenarios in California; the "KF" is used in a parametric, deterministic-Montecarlo, way. The Montecarlo technique is applied to eleven source parametres of the "KF" formula. In so doing, we obtain several tenths of thousands of sources to calculate each scenario, allowing us to take into account the variabilities of the sources within the considered seismotectonic settings. In particular, our scenario sources include all sources that were found from instrumental measurements, independently from our work. The validation of our scenarios is performed by quantitatively comparing our intensity scenarios with the site intensities observed by the U. S. Geological Survey in the field. Then, we also produce the traditional scenarios obtained by the widely used attenuation of intensity with distance, and make a quantitative comparison with our KF scenarios; this is done by computing the intensity residuals at the surveyed sites. Our scenario is slightly better then the traditional one for the Northridge, 1994 earthquake; on the other hand, there is a significant improvement for the Loma Prieta, 1989 event. This is due to the compact shape and the up-dip directivity of the former source, as well as to the extended shape and horizontal directivity of the latter one. Regarding this, we recall that our simplified model is able to simulate only the horizontal directivity (to avoid overparametrization when treating the pre-instrumental earthquakes).

### STOCHASTIC FINITE-FAULT GROUND MOTION SIMULATIONS AT MT VESUVIUS INFERRED BY LOCAL EARTHQUAKES – ID 1705

*D. Galluzzo, INGV, Italy*
*G. Zonno, INGV, Italy*
*E. Del Pezzo, INGV, Italy*

The stochastic technique used in this work is based on the finite-fault simulation method FINSIM (Beresnev and Atkinson, 1997, 1998b). This method assumes that the fault plane is a rectan-

gle, subdivided into an appropriate number of sub-faults, which are modelled as point sources characterized by an omega^2 spectrum. The sub-fault moment and corner frequency are derived from the size of each sub-fault and the number of triggered sub-faults is adjusted so that the specified target moment is achieved. The simulations are evaluated for 15 local earthquakes ($2.0 < ML < 3.6$) occurred at Mt. Vesuvius during the 1999 seismic crises and recorded at three components digital seismic stations equipped with a short period sensors (1 Hz). The main input parameters of the stochastic model are the fault geometry, the average elastic properties of the propagation media, such as crustal shear velocity, density and attenuation factors, and source related parameters as seismic moment and stress parameter. Site effect estimations are obtained with classical spectral ratios method applied on horizontal components of motion. The sub-fault dimension dl and stress drop are fixed with "trial and error" procedure by comparing synthetic waveforms and Response Acceleration Spectra (PSA, 5% damping) with the observed ones evaluated on real seismograms. This procedure is applied for BKE station and is checked with other available stations. The empirical relations dl vs ML and stressdrop vs ML can be used for the evaluation of peak ground motion and response spectra for seismic events with $ML > 3.6$. The resulting ground motion parameters can be considered a critical seismic hazard estimation factor for the investigated area.

### HYBRID MODELLING OF GROUND MOTION – ID 759

*E. Gottschämmer, Geophysical Institute, Karlsruhe University, Germany*
*A. Oth, Geophysical Institute, Karlsruhe University, Germany*
*J. Miksat, Geophysical Institute, Karlsruhe University, Germany*
*F. Wenzel, Geophysical Institute, Karlsruhe University, Germany*

The Vrancea region (Romania), located in the Carpathian Arc, is one of the seismically most active regions in Europe. Within the framework of the CRC 461 'Strong Earthquakes: A Challenge for Geosciences and Civil Engineering' funded by the German Research Foundation (DFG) we try to understand the tectonic processes that are responsible for the strong intermediate depth earthquakes in order to develop realistic models and predictions of ground motion.

However, as in other continental regions, the data base of large earthquakes is rather scarce. A forward modelling approach using Finite-Differences (FD) was successfully performed by Miksat et al. (2006). The FD-method, due to computational limitations, was in this case restricted to frequencies below 4.5 Hz. Oth et al. (2006) simulated ground motion for the MW = 5.9 Vrancea earthquake (October, 27, 2004) using Irikura's simulation technique. It is based on the concept of self-similarity and assumes constant stress drop for small (MW in the order of 5.0) and large (MW up to 2 magnitude units larger) earthquakes. The small earthquakes are used as empirical Greens's functions to model ground motion of large events. Yet, with this method, ground motion is only available at those locations where small events have been recorded.

We develop a hybrid modelling method that can overcome those shortcomings. We use Fourier acceleration spectra computed from data recorded during the last large events in 1977, 1986 and 1990. Additionally, we include spectra obtained from forward modelling with FD and Irikura's method in our inversion. In the spectral domain, we invert for the free parameters and use these parameters to model ground motion then with a stochastic method. Thus, this new approach allows us to model area-wide ground motion that integrates information obtained from large and small events, as well as our knowledge about the subsurface structure.

## SC-F 1-II: Approaches to Model Seismic Scenarios

Friday 13:30 - 15:00 – Room 22

### SEISMIC SCENARIOS IN TERMS OF MACROSEISMIC INTENSITY – ID 1934

*R. Rotondi, CNR-IMATI, Italy*
*G. Zonno, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

Our aim has been to carry out a complete probabilistic analysis of the problem of the intensity attenuation. The procedure followed starts from the intensity data points of some earthquakes and arrives at the assessment of the probability distribution for the intensity at site given the epicentral intensity and the site-epicenter distance. No a priori assumptions have been done concerning both empirical attenuation laws and zonation. We have considered a test set of 55 earthquakes covering the entire Italian territory with epicentral intensity from VII to XI degree of the MCS scale. An explorative analysis of this data set has been performed to partition it in all possible clusters of events with similar attenuation trend. For each decay degree we have assumed median, mean, and 75% quantile of the set of the site-epicenter distances as representative variables of the attenuation trend. An agglomerative method (Kaufman and Rousseeuw, 1990) allowed us to partition the test set in three classes of earthquakes identified, hence, as similar from the attenuation viewpoint. Such classes have been used as learning set to build prior distributions of the model parameters in the Bayesian framework. The probabilistic model used for the intensity at site, or equivalently the decay, is that presented in Rotondi and Zonno (Annals of Geophysics, 47, 5, 1521-1540, 2004), where the semi-qualitative character of the intensity is emphasized by the application of the binomial distribution for the intensity at site. In this way we were able to give the predictive probability distribution of the decay at any distance given the epicentral intensity of an earthquake with different attenuation trend. The validation has been performed through probabilistic measures of the fit, like scoring rule and odds ratio, following a cross-validation technique.

### THE ATTENUATION OF SEISMIC INTENSITY IN ITALY: MODELING AND VALIDATION – ID 1855

*C. Pasolini, Dip. di Fisica, Univ. di Bologna, Italy*
*D. Albarello, Dip. Sc. della Terra, Univ. di Siena, Italy*
*P. Gasperini, Dip. di Fisica, Univ. di Bologna, Italy*
*V. D'Amico, Dip. Sc. della Terra, Univ. di Siena, Italy*
*B. Lolli, Dip. di Fisica, Univ. di Bologna, Italy*

The characterization of intensity decay with distance from the source is of paramount importance for seismic hazard assessment and to earthquake damage scenarios necessary for the management of prevention activities. In the recent literature, a renewal of interest about this problem is occurring in particular as concerns the Italian region where different parameterizations have been proposed. The significant scatter between these relationships suggested a re-analysis of the problem in order to overcome most significant drawbacks that characterised previous approaches, as discussed in a companion presentation. As a first step the analysis aimed at the definition of an isotropic attenuation relationship valid for the whole Italian area. Since this attenuation relationship has to be primarily used in probabilistic seismic hazard assessment, major attention has been devoted to evaluate attenuation relationship in its complete probabilistic form. An important aspect has been the preliminary evaluation of the "intrinsic" scattering of data (i.e. the one independent of specific attenuation relationship to be used), which represents the lowest threshold for the variance to be explained with the attenuation relationship. Furthermore, to reduce possible biases, completeness of the available database has been checked and a suitable data selection has been performed. Since epicentral intensity cannot be defined unambiguously from the experimental point of view, the attenuation relationship has been scaled with a new variable more representative of the earthquake dimension. Several criteria have been considered to evaluate competing attenuation formulas (ANOVA, BIC, AIC, etc.) while statistical uncertainty about empirical parameters has been evaluated by using standard approaches and bootstrap simulations. At last, the performance of the selected relationship has been analysed by using a distribution-free approach.

### MACROSEISMIC INTENSITIES FOR SEISMIC SCENARIOS, ESTIMATED FROM INSTRUMENTALLY BASED CORRELATIONS – ID 569

*E. Faccioli, Dept. Structural Eng., Politecnico di Milano, Italy*
*C. Cauzzi, Dept. Structural Eng., Politecnico di Milano, Italy*

We deal here with the task of realistically assessing macroseismic intensities of historical earthquakes causing significant damage to cities, from the perspective of using such assessment in the construction of earthquake damage scenarios. As is well known, the latter are critically influenced by the uncertainties that inevitably affect the intensity assessments based on the interpretation of written and other historical records, often resulting in an overestimation of the severity of ground shaking. To cope with this shortcoming, a very carefully selected and documented set of observations is used to develop two empirical correlations based on instrumental data (mostly from Italian earthquakes): one using magnitude and distance as independent parameters, and the other a ground motion parameter (maximum velocity or acceleration). The input data and results of a preliminary previous study are here significantly updated and improved: 1. by introducing a well known technique in regression analysis, the determination of magnitude dependence is decoupled from the determination of distance dependence; 2. macroseismic intensity data entries are critically revised in order to use only comparable intensity scales; 3. particular attention is paid to the homogeneity of the data set distribution in magnitude and distance. The differences with respect to the instrumentally based correlation developed in California for shake-maps evaluations are analyzed and discussed. The application of the correlations obtained is illustrated for the case history of Catania city (Italy), suffering destruction by a late 17th century earthquake for which extensive historical documentation of damage exist.

## SC-F 3-I: Multiparametric Test Sites in Europe for the Evaluation of Ground Motion Amplification

Tuesday 13:30 - 15:00 – Room 7+8

### THE TURKEY-FLAT EXPERIMENT - 2004 PARKFIELD EARTHQUAKE STRONG MOTION "BLIND" PREDICTION – ID 1888

*I. Oprsal, Charles University, Czech Republic*
*J. Zahradnik, Charles University, Czech Republic*

This is a part of the international blind prediction experiment (California Geological Survey, 2005) of the M6, Sep. 28, 2004 Parkfield earthquake. Strong motion data at Turkey flat site, based on knowledge of real records from two stations (R1, D3, respectively), are predicted. Acceleration time histories, Fourier spectral ratios, peak ground motion values, and response spectra at other stations (R2, V1, V2, D1, D2, D3), inside or around a shallow stiff-soil sedimentary valley of Turkey Flat, are studied. In contrast to the most widely used philosophy of experiments like this, where main focus is on local site effects while the excitation is represented by plane incident waves, our trick is to emphasise the source effect. The available strong motion data (CISN) at R1 are modelled. Composite-source predictions utilized a non-uniform fault slip distribution (Ji, 2005). Local effects are treated in simplified way using individual 1D models below each receiver. Such simplified treatment is possible since the 3D structural heterogeneity is small. Our predictions combine the fault rupture, crustal wave propagation, and 1D local site effects, at 0 to 40 Hz band.

### INTERPRETATION OF MICROTREMOR H/V RATIO IN MULTILAYERED MEDIA: A STUDY AT HAIFA BAY, ISRAEL – ID 153

*Y. Zaslavsky, Geophysical Institute of Israel, Israel*
*M. Gorstein, Geophysical Institute of Israel, Israel*
*T. Aksinenko, Geophysical Institute of Israel, Israel*
*M. Kalmanovich, Geophysical Institute of Israel, Israel*
*G. Ataev, Geophysical Institute of Israel, Israel*
*V. Giller, Geophysical Institute of Israel, Israel*
*I. Dan, Geophysical Institute of Israel, Israel*

In the framework of a microzoning study of the Haifa Bay, which is close to a major seismogenic zone of the Dead Sea Rift, a methodology based on integration of H/V microtremor measurements and 1D linear model using SHAKE was applied in order to characterize seismic behavior of sediments. Major geological features of the study area include sub-parallel horsts and grabens dissected by faults; the absence of a common reflector for the whole area; the presence of five lithological units, which may be considered as potential local reflectors; intermediate hard layers in addition to the main reflector at most of the analyzed sites and overall sediment thicknesses varying from 10 m up to 600 m. From microtremor measurements conducted at 480 locations in an area of about 50 km2 horizontal and vertical component spectral ratios were derived. The results show two H/V peaks at frequencies related to resonances of deep and shallow structures. Spatial variations of the frequency (0.5-5 Hz for the first peak and 1-8 Hz for the second peak) and H/V amplitude level (2-3 for the first peak and 2-15 for the second peak) reflecting the geological complexity are shown in four distribution maps. Limited data on sediment thickness and velocities were available from a few refraction surveys and boreholes. Transfer functions calculated for models based on these data were used to validate H/V ratios at corresponding locations and justified their further utilization, by velocities extrapolation, to study other sites, away from refraction lines and boreholes. There, layer thicknesses were sought, yielding calculated transfer functions to match the observed H/V curves, considering all response peaks. The modeling results are represented graphically in the geological cross sections characterizing the study area. In some cases, these models suggest a revision of existing concepts as regards the subsurface structure in the region.

### SPATIAL VARIATION OF GROUND MOTION IN ISTANBUL – ID 1988

*E. Harmandar, Kandilli Observatory and Earthquake Research Inst., Turkey*
*E. Durukal, Kandilli Observatory and Earthquake Research Inst., Turkey*
*M. Erdik, Kandilli Observatory and Earthquake Research Inst., Turkey*
*O. Ozel, Kandilli Observatory and Earthquake Research Inst., Turkey*

The spatial variation of earthquake ground motions can occur as a consequence of soource properties, wave propagation through different earth strata, soil media and topographic features and serves to quantify the amplitude and phase differences of ground motion over distance or area. The spatial variation of earthquake ground motion has an important effect on the response of linear lifelines such as bridges, pipelines, communication systems, and should preferably be accounted for in their design. In this study, spatial variation of strong-ground motion in Istanbul from two earthquakes recorded by the Istanbul Earthquake Rapid Response and Early Warning System (IERRS) is analyzed. The first event (ML 4.3) took place on 16.05.2004 off the Yalova coast in the Eastern Marmara Sea. The second one (ML 4.0) occurred on 29.09.2004 to the south of the Prince islands. The spatial variance of motion within the network is investigated by the analysis of the intra-event variation of peak horizontal accelerations (PHA) and pseudo spectral velocities (PSV), as well as by coherency analysis. The intraevent spatial variability of PHA's is examined by the PHA ratio of two stations as a function of separation distance over a frequency range of 0.2 to 25 Hz. The analysis is repeated using ratios of PSV's of station-pairs calculated as the average of PSV's between 0.2 and 1.0 s periods for 5-percent critical damping, and plotted against station-separation distance. . We also compared the coherency results with the other related studies. The results are preliminary in the sense that so far two events were recorded by the larger number of stations in the IERRS This work forms the

skeleton of an automated system to uniformly calculate the variance of recorded motions. It is expected that the results obtained will stabilize and become more reliable as the number of recorded events increase.

### SITE EFFECT INVESTIGATIONS BASED ON THE DEAD SEA TRANSFORM EARTHQUAKES ML=5.2 ON FEB. 11, 2004 AND ON JUL. 7, 2004 – ID 1639

*Y. Zaslavsky, GII, Israel*
*R. Hofstetter, GII, Israel*
*N. Perelman, GII, Israel*

The phenomenon of seismic wave amplification due to sedimentary deposits and topographical conditions constitutes a major factor in damage and loss during strong earthquakes. In the present study we concentrate on evaluation of site effects at the sites where two local earthquakes that occurred 11.2.2004 and 7.7.2004 along the Dead Sea transform triggered strong motion accelerometers and were recorded by three-component short and broad band seismic stations operated as part of the Israel Seismic Network. The horizontal-to-vertical (H/V) component spectral ratio of earthquake shear wave (receiver function estimates) was used to approximate the fundamental resonance frequencies of the subsurface and their associated amplitude. Amplification effects by near-surface geological conditions of factor 4-6 are observed at various frequencies in the 0.8-4 Hz band. These data were used to constrain 1-D subsurface models that developed using geological and geophysical information. The seismic station located on the high plateau near top escarpment and on small mountains and hills amplified the motion in the frequency range 1.0-3.0 Hz with a factor of up to 5. At these sites we observe great differences between N-S and E-W components. These earthquakes add significantly to our knowledge about the influence of the effects of local geology and topographic prominences on the amplitude of seismic waves. Our results show that receiver functions may be also useful for describing the frequency and topographical amplification.

### SITE EFFECT INVESTIGATION IN URBAN AREAS: THE POTENZA TEST SITE (SOUTHERN ITALY) – ID 1721

*A. Strollo, GFZ, Germany*
*M. Mucciarelli, USB, Italy*
*S. Parolai, GFZ, Germany*
*R. M. Gallipoli, IMAA-CNR, Italy*
*S. M. Richwalski, GFZ, Germany*
*D. Bindi, INGV, Italy*

The city of Potenza is located in the Southern Appennines (Italy) and has currently 70.0000 inhabitants. In the last 25 years three damaging earthquakes affected this area. The Irpinia earthquake (1980) reached intensities VII-VIII MCS inside the urban area of Potenza; the 1990 and 1991 earthquakes yielded a maximum observed intensity of VI MCS. The city lies over a complex geo-morphological area (different kinds of soil, flat alluvial valleys surrounded by steep hills) and therefore a detailed study of the effect of both local geology and topography on seismic ground motion is necessary in order to investigate, which areas will be more prone to damage in case of an earthquake. For these reasons, the city of Potenza was selected for preparing ground motion scenario within the DPC-INGV S3 project. To do this, 11 stations composed of Reftek 72A data acquisition system and Mark L-4C-3D sensors were installed within the urban area for recording seismic noise and earthquakes. The Network had recorded 252 earthquakes continuously since middle of October 2004 to May 2005. Different techniques were used in order to evaluate the site response. In a first step, the H/V spectral ratio technique was applied to both noise and earthquake recordings. In general we found that the results obtained from different data sets were consistent. Although the site response varies significantly in the investigated area, even at neighbouring sites, the results show for most of the amplified sites an amplification in the frequency range 2-5 Hz. The largest peak is observed on top of fluvial sediments (Rai TV). In the second step, site responses were calculated by applying the Generalized Inversion Technique. Finally, for some of the investigated sites the site response was compared with soil characteristics, historical damage and with theoretical site response derived from geotechnical and geophysical parameters.

### INFLUENCE OF GEOLOGICAL PROPERTIES ON QUANTITATIVE MICROZONATION IN THE AREA OF BASEL; RESULTS FROM A MULTIPARAMETRIC STUDY – ID 1722

*P. Huggenberger, Dept. Environmental Sciences, Switzerland*
*E. Fäh, Dept. Environmental Sciences, Switzerland*
*D. Fäh, Swiss Seismological Service, Switzerland*
*H. B. Havenith, Swiss Seismological Service, Switzerland*
*B. Steiner, Swiss Seismological Service, Switzerland*

The Basel area in the NW of Switzerland is located at the southern edge of the upper Rhine Graben and its related Cenozoic rift system that is bounded to the south by the fold-and –thrust belt of the Jura Mountains and to the east by the Tabular Jura. The background seismicity in the Graben is modest compared to the overall seismic activity of Southern Europe. However, the earthquake of 18 October 1356 is the largest event recorded in central Europe. A recurrence time of this earthquake magnitudes in the Basel area was estimated to be in the order of 1500 to 2500 years. As the effects of surfical geology on seismic motion could be large, there have been significant efforts to better understand the differences in vulnerability with respect to the distribution of subsurface parameters. Since the publication of the qualitative microzonation map of the city of Basel in 1999, a quantitative microzonation study of an extended area, including the dense populated river valley Birs, Ergolz, Rhein and Wiese was initiated within the framework of the European INTERREG III program. The quantitative microzonation takes into account the present knowledge of the geophysical processes as a function of subsurface geology (amplifications of groundmotions and fundamental frequencies). The different geological parameters have been determined based on analysis of several thousand drill-core data deriving from the geological database of the University of Basel. A comparison of the distribution of the different geological parameters and the geophysical data of the various measurements allow to distinguish a series of zones, for which different behavior with respect to seismic motions is expect. Factors affecting frequency and amplification are discussed. In addition, a map of phenomena supplements the zonation map with site-specific geological-geotechnical information relevant for engineering purposes.

## SC-F 3-II: Multiparametric Test Sites in Europe for the Evaluation of Ground Motion Amplification

Tuesday 15:30 - 16:15 – Room 7+8

### 1D VERSUS 3D HYBRID MODELLING OF SITE AND PRONOUNCED TOPOGRAPHY EFFECTS FOR THE ARCHAEOLOGICAL SITE OF AUGUSTA RAURICA, SWITZERLAND – ID 1885

*I. Oprsal, Charles University, Czech Republic*
*D. Fäh, ETH, Switzerland*

Numerical modelling using 1D and 3D techniques has been applied to the Roman city of Augusta Raurica, located East of Basel, Switzerland. One important topic of the city's history concerns the hypothesis of an earthquake striking the city in the middle of the third century A.D. The 3D finite-difference (FD) method computes the full 3D wave field by a hybrid approach on an irregular grid. Topography is included in the modelling. The 1D-matrix method is used to model the P-SV response for 195 x 213 1D structures extracted from the 3D computational model by retrieving a vertical profile under each surface point. The

incoming wave field is realized by a vertically incident planar wave for a family of sources. The established three-dimensional velocity structure for the studied area comprises (as geophysical bedrock) a limestones unit (Muschelkalk), tertiary sediments (Keuper), and Quaternary gravel layers. The area is characterized by a pronounced topography. The soft-sediment cover is typically not thicker than 50m. Pseudo-spectral response amplification (PSAA, 5%-damping) for frequencies between 0.1Hz and 10Hz shows values up to factor 4.6 in the 1D case and up to factor 9.1 in the 3D computations. The locations of the largest amplifications differ between the 1D and 3D method. Thus the 3D - vs.1D- amplification is expressed by a ratio of about 2.5, usually at the top of the most pronounced topographic features within the Quaternary formation.

### A PRELIMINARY STUDY FOR THE DISTANCE DEPENDENCE OF THE SPECTRAL DECAY PARAMETER K FOR THE EUROSEISRISK STRONG MOTION ARRAY – ID 1907

*C. Papaioannou, ITSAK, Greece*

The Fourier amplitude spectra of selected accelerograms recorded by the 3D strong motion array at the EUROSEISRISK (Northern Greece) study area were used for the study of the distance dependence of the parameter $\kappa$. The spectral decay technique was used for the estimation of the decay parameter kappa of the high frequency acceleration spectra. The data set used consists of 272 horizontal components with epicentral distances in the range of 1 km $<$ R $<$199 km. Following the spectral analysis of the waveforms, relations holding for the distance dependence of kappa were determined for various soil types. The parameter $\kappa o$ for every recording site was also determined. The analysis was carried out using an interactive tool, which enables the trial of various windows selection in the time domain for the analysis and then the data elaboration in the frequency domain. The length of the window of the selected signal in the time domain depends on the epicentral distance and magnitude of the corresponding earthquake In order to investigate the variations of $\kappa o$ with the soil conditions the data were plotted for stations having the same conditions. The value determined for the stations located along axis of the valley (thick deposits) was found equal to 85msec, for the station at "very stiff soil", $\kappa o$ found equal to 49 msec, while for the transition area at the edges of the valley the value was found equal to 66.5 msec. The data analysis in the frequency domain resulted also in the estimation of the frequency f95 (: frequency which defines the upper limit of the frequency band including the 95% of the energy) and the fmax. The results for the EUROSEISRISK array were compared with the results obtained for other areas in Greece and the comparison shows that the Mygdonia graben, where the EUROSEISRISK array is deployed has the highest attenuation among the examined areas.

### CAN THE BALLISTIC- DIFFUSIVE TRANSITION IN THE SEISMIC NOISE-FIELD BE SEEN AS A SITE RESONANCE FREQUENCY DETECTOR? – ID 1774

*A. Caserta, Isituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Govoni, Osservatorio Geofisico Sperimentale, Italy*
*S. Parolai, GeoForschungsZentrum, Germany*

The analysis of the statistical properties of the seismic noise-field shows that two dynamical regimes are present at the same time: the ballistic and the diffusive regime. One regime can be predominant in respect to the other one according to the site conditions, i.e., according to the level of heterogeneities on small scale. An ad hoc experiment has been designed and realized to measure in different sites, the diffusive constant versus frequency. It has seen that the ballistic-to-diffusive transition takes place at frequencies that can be thought as resonance frequencies of the site.

## SC-F 4: Geoinformation Technologies Oriented to Seismic Hazard and Seismic Risk Assessment

Monday 13:30 - 15:00 – Room 3

### GIS BASED EARTHQUAKE DISASTER MANAGEMENT AND MITIGATION INFORMATION SYSTEM (EDMMIS) – ID 719

*B. Sarma, Jorhat Engineering College, India*

The northeastern region of India is recognized as being highly seismic and two of the worlds most severe earthquakes of 1897 and 1950 have occurred in this region. The earthquake risk assessment and mitigation is a multidisciplinary task and requires collateral approach and collection of huge amount of data in different fields, its integration and interpretation. There is a strong need of application of space technology integrated with GIS technologies to create a global digital database containing urban sprawl information, available land for urban growth, the rate of land development and land use change, information regarding bedrock profile, liquefaction potential information etc. for Disaster Mitigation and Management Planning. In India, this process has been initiated in different cities including the city of Guwahati situated in a very high seismic zone (Zone V). In this study, a probabilistic seismic hazard map is prepared on GIS platform through the overlaying and subsequent integration of the Shear wave velocity (SW) site classes, Geology and Geomorphology (GG), Basement (B), Landslide Zones (L),and the seismological themes such as Site Response (SR), Peak Ground Acceleration(PGA) and Predominant Frequency(PF). This database comprises of general principle of risk analysis, integration of seismic hazard/vulnerability data, equivalent damage ration (EDR) and index for people living in structures susceptible to damage, damage to different lifeline structures, retrofitting procedures etc. Finally, a Remote Sensing and GIS based Earthquake Disaster Management and Mitigation Information System (EDMMIS) is designed to provide facilities to the planning authorities to take strategic decisions and to set guidelines regarding the new constructions and vulnerability assessment of the existing structures. This database and methodology can be used as a stepping-stone in the process of the preparation of a Global Information System for earthquake risk assessment and its preparedness considering various likely earthquake scenarios in the world.

### GIS-BASED JAPAN ENGINEERING GEOMORPHOLOGIC CLASSIFICATION DATABASE FOR SEISMIC HAZARD ASSESSMENT – ID 762

*K. Wakamatsu, Kawasaki Laboratory, NIED, Japan*
*M. Matsuoka, EDM, NIED, Japan*

After the 1995 Kobe earthquake, nationally available earthquake-damage assessment systems were developed in Japan and are now being used by government and other public and private organizations. Under these systems, ground conditions play important roles in the evaluation and forecasting of hazards. However, neither digital databases nor paper maps of ground conditions throughout Japan have been available in a unified form. Thus, to evaluate seismic hazards for a wide area systematically, the authors have developed a 30-arc-second "Japan Engineering Geomorphologic Classification Map (30-arc-second JEGM)" for hazards nationwide; this is the first nationally standardized GIS database for ground conditions in Japan (Wakamatsu et al. 2004). The digital data of the JEGM were released in November 2005 (Wakamatsu et al. 2005). To perform more accurate hazard zoning, we have been developing a 7.5-arc-second Japan Engineering Geomorphologic Classification Map (7.5-arc-second JEGM) for the whole of Japan, which is a high spatial-resolution version of the above-mentioned 30-arc-second JEGM. In this paper, the outline of the 7.5-arc-second JEGM and its utilization for nationwide seismic hazard assessment will be presented, including site amplification and soil liquefaction. The resulting maps can be

useful for evaluating the approximate areas affected by hazards and for disaster prevention planning.

### RISK ASSESSMENT FOR THE ROAD NETWORK IN THE FRENCH-ITALIAN BORDER REGION USING WEB SERVICES – ID 827

*J. Douglas, BRGM, France*
*J. J. Serrano, BRGM, France*
*D. Coraboeuf, BRGM, France*
*F. Robida, BRGM, France*
*H. Modaressi, BRGM, France*
*M. Atkinson, Joint Research Centre, Italy*
*G. Vowles, Ordnance Survey, UK*
*I. Holt, Ordnance Survey, UK*

The EC Framework Programme 6 Integrated Project ORCHESTA (Open Architecture and Spatial Data Infrastructure for Risk Management, http://www.eu-orchestra.org/) is concerned with the creation of an information technology architecture and associated web services for risk management. Its aim is to improve the interoperability of risk management data and software and lead to international software standards (similar to those provided by the Open Geospatial Consortium) in the context of the EC INSPIRE directive. In particular, multi-risk and cross-border issues are addressed since these are important within the European context. In order that the outcome of the project is useful in real-life risk management situations a number of pilot projects are planned to test parts of the developed system. It is also hoped that these pilots will demonstrate the utility of the ORCHESTRA project to end users.

This paper discusses the pilot project being undertaken by BRGM, JRC and Ordnance Survey with the collaboration of local partners in the French-Italian border region between Nice and Genoa. The basis of the project is the evaluation of risk to the road network and the impact of road network disruption by, for example, earthquakes, landslides, floods, fires and chemical spills. Road closures can have a dramatic impact on the economic, social and functional life of a region and these impacts can spread far from the site of the blockage and, even, across international borders. The region chosen for this pilot project is especially prone to hazardous events and also, due to the lack of redundancy in the road network within the region, disruption to a major route can have a large effect. This pilot will seek to create a distributed network of web services that will access hazard, route and traffic information held within databases based at the data providers.

### ELECTROSTATIC IMAGING TO DETECT POSSIBLE EARTHQUAKE PRECURSORY STRUCTURAL CHANGES – ID 1623

*B. Ustundag, Istanbul Technical University, Turkey*
*O. Kalenderli, Istanbul Technical University, Turkey*
*H. Eyidogan, Istanbul Technical University, Turkey*

A network of 25 on-line stations that contains monopolar electric field probes was installed around Northern Anatolian Fault to detect earthquake precursory electrical anomalies beginning from 1999. Electrodes of the probes are intended to measure electrical displacement between the upper lithosphere and the lower atmosphere. Two strategies are used to show the relationship between the earthquakes and the monopolar electrical displacement measurements. The first is SOM type artificial neural networks those construct the relationship between the measurement patterns and the seismic events. This is useful if we consider that model uncertainty is high. Although it is practical and relatively simple, it requires supporting data in order to speed up the teaching phase. Otherwise too many correlating events are needed for each region. The second method is analytic investigation of the signals in order to catch specific precursory processes. Dilatency is the main example to those precursory structural changes. We propose a sort of passive electrostatic imaging in time to detect beginning and rate of the structural change. In electrical engineering, "electrostatic imaging" requires a known electrical charge source and a coupling measurement probe. If the probe is mobile in space then the induced electrical charges on the electrode will be a function of dielectric coefficient change of the material between the supply and the scan trajectory. The same feature holds for the lithosphere of the Earth since there is always equivalent internal charge distributed in layers. Non-stationary character of the background electric field is the main problem of passive electrostatic imaging. For this reason we collect long term data from fixed stations instead of mobile measurements. Hence we get the long term development of periodic components and compensate the patterns to be evaluated. Discontinuities and period deflections of the patterns have significant correlation to the seismic events as shown in examples.

### GEOTIME II: A WEB-GIS FOR A COMPLEX ANALYSIS OF SPATIO-TEMPORAL PROCESSES – ID 537

*V. Gitis, Institute for Information Transmission Problems, Russian Federation*
*A. Derendiaev, Institute for Information Transmission Problems, Russian Federation*
*P. Metrikov, Institute for Information Transmission Problems, Russian Federation*

Web-GIS GeoTime II is a new system designed for a complex analysis and forecasting of spatio-temporal processes. The system is implemented as Java 1.5 program (applet) and is included in a Web page. In loading such a page, the system is automatically installed into user's computer and starts operating. Java-applets can operate on any platform provided with standard Internet browsers. Web-GIS GeoTime II is defined as distributed network geoinformation environment, which can utilize the data and program modules (pluggins) set up in widely separated web-servers and user's computer, as well as can save the results on the user's computer. The system supports operations with vector-based, 2D, 3D, and 4D grid-based data. Exploration of spatio-temporal processes supports with the methods of interactive visual exploration, a wide set of spatial and spatio-temporal data transformations, and plausible inference based on multidimensional statistics, pattern recognition, fuzzy calculations and simulation technique.

Geoinformation network technology for analysis of spatio-temporal processes and case studies of web-GIS applications to seismic hazard assessment, estimation of seismic damages, and analysis of earthquake precursors are discussed.

The work was partly supported by RBRF projects 03-07-90114, 04-07-0155, 06-07-89139 and by Basic researches program of Presidium of RAS 21, section "Electronic Earth".

### GIS BASED DATABASE AND TOOLS DEVELOPED FOR THE SEISMICITY STUDIES AND SEISMIC HAZARD ASSESSMENT OF GEORGIA – ID 1436

*M. Elashvili, UNSSP, Georgia*
*Z. Javakhishvili, UNSSP, Georgia*
*T. Mumladze, UNSSP, Georgia*
*T. Godoladze, UNSSP, Georgia*

The analysis of the historical and instrumental seismicity of Georgia shows, that this is the region of moderate seismicity. The strong earthquakes with magnitude up to 7 and macrosiesmic intensity 9 (MSK scale) occurred here. The reoccurrence period of such event is of order 103-104 years. The seismicity pattern is well correlated with map of active faults of Georgia and fault plane solutions of moderate and large events are in agreement with general seismotectonic feature of region. Also we can state some seismic activity increase in the region, connected with resent destructive events. Multifunctional database based on seismological, Geophysical and Geological features was created in ArcView 3.3 software. Special tools were developed in GIS, aiming temporal and space analysis of seismicity as well as probabilistic seismic hazard calculations. Computer program SEISRISK III after Bender and Perkins 1987 and, was integrated in GIS, allowing us to use all the advantages of modern technologies.

## SC-F 5-I: Seismic Hazard and Risk due to Induced Seismicity

Friday 10:45 - 12:15 – Room 18

### MAN-MADE EARTHQUAKES - A SERIOUS GEO-ECONOMIC FACTOR – ID 717

*C. Klose, Columbia University, United States*

The seismological spotlight has been generally on natural earthquakes but hazards and risks caused by man-made earthquakes were given relatively little scientific and public attention. A world-wide compilation of strong (Mw > 5) natural and man-made earthquakes reveals that triggered seismicity occurs mostly in stable continental regions (SCRs) such as many parts of America, Eurasia, Africa or Australia. SCR-earthquakes show a bimodal depth distribution with a very shallow upper crustal component (< 7 km). Their focal depths are generally over-estimated (often by 100%), due to sparse national seismic networks. These and other facts have been partly hidden with systematic hazard under-estimations of man-made earthquakes exemplified in a cost-benefit analysis based on 200 years coal mining in New South Wales (Australia). Black coal mining weakened and reactivated a major fault beneath the Newcastle coal field thereby triggering the 1989 M5.6 Newcastle earthquake. The earthquake caused more than 3.5 billion U.S. dollars damage and Australia's first and to date only earthquake fatalities. Elevated levels of geomechanical pollution (GMP) induced by mining and other industrial processes have accelerated throughout the second half the 20th century and can be considered as a serious geo-economic factor.

### PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR MINING-INDUCED SEISMICITY – ID 1882

*S. Lasocki, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*

The probabilistic seismic hazard analysis (PSHA) is a standard tool to estimate expected seismic impacts of earthquakes. Mining-induced seismicity, however, significantly differs from the earthquake process. The occurrence of seismic events is predominantly controlled by time-varying mining works, therefore the active zones in mines are transient. Moreover, even during their lifetime, the activity of these zones changes considerably. We have modified the standard PSHA procedure so that it is applicable also to mining-induced seismicity areas. In this modified procedure, locations and times of activity of the zones that will be active in the future are deduced from programs of mining operations. Probabilistic characteristics of these zones are inferred from weighted characteristics of the zones that were active in the past. The weights correspond to the degree of similarity in mining and geological conditions between the past zones and the future ones. We present the details of this approach, and an example of its application to an actual problem evoked by mining-induced seismicity in the Legnica-Głogów Copper District in Poland. Several thousands events occurring yearly in three copper mines located in this region, the strongest being of local magnitude more than 4.0, create a serious problem for the safety of ground structures. Among such structures is Żelazny Most ore flotation wastes repository, whose present capacity is more than 350 million m3 of mineral wastes. We used PSHA to provide design values of peak ground acceleration along the embankments for the next 20 years. Particular attention was given to expectable seismicity of one area of future mining works, which would be located very close to the repository. In this case the analysis was supported by expert judgment regarding the anticipated characteristic of future seismicity, and different possibilities of the process development were combined with the logic tree approach.

### SEISMICITY AND SEISMIC HAZARD STUDY FOR ENGOURI HIGH DAM AREA – ID 1451

*Z. Javakhishvili, United National Survey for Seismic Protection, Georgia*
*T. Godoladze, United Survey for Seismic Protection of Georgia, Georgia*
*M. Elashvili, United Survey for Seismic Protection of Georgia, Georgia*

The height of Enguri high arc dam is 271 meters. It is located in seismically active region. The first stage of reservoir filling begun in April of 1978 and the number of small earthquakes of surrounding territories rapidly increased. After 1.5 year from the beginning of reservoir filling two moderate earthquakes, with magnitude 4.3 and 4.7, and their aftershocks occurred. On October 6, 2005 at 21 75 local time (17:57 UTC) an earthquake with magnitude M=4.8 occurred in western Georgia in the vicinity of Enguri High dam. The mainshock was preceded by the foreshock with M=3.6 at 16:17 UTC. These earthquakes, as well as several aftershocks, were recorded by seismic network of Georgia. The epicenters of these events situated very close to each other. The coordinates of the main shock were: N=42.836 and E=42.203, focal depth - 10 km and for the foreshock N=42.836 and E=42.228, focal depth 7 km. The epicenter of the main shock situated at a distance of about 15 km from the Enguri High Dam and town Jvari. The earthquake was recorded by the strong motion seismographs installed on the crest of the dam. Detail analysis of natural frequencies and other dynamical characteristics of the dam were performed. We used results to calculate High Dam hazard scenario in Case of strong Earthquake. Our aim is to create two dimensional water distribution model based on real topography of adjacent territories. Some work on this direction was already done, but only for one-dimensional case, up to 15 calculation models were tested and most efficients were selected for further modeling. Topography of adjacent territory was created in GIS using 1 : 50,000 scale maps.

### SEISMIC HAZARD DUE TO SMALL-MAGNITUDE, SHALLOW-SOURCE, INDUCED EARTHQUAKES IN THE NETHERLANDS – ID 2008

*T. Van Eck, KNMI, Netherlands*
*F. Goutbeek, KNMI, Netherlands*
*H. Haak, KNMI, Netherlands*
*B. Dost, KNMI, Netherlands*

The Netherlands has large on land gas reservoirs, which are being exploited since 1960. Small-magnitude (ML $\leq$ 3.5), shallow (depth < 4 km) events induced by this gas exploitation cause light damage and much concern to the regional population. As one of the consequences the Dutch law requires since 2003 seismic hazard and risk estimates for each mining concession. Up to now only general quantitative hazard estimates, maximum possible earthquake and maximum possible intensity were available. Here we provide more specific quantitative hazard estimates. A long-term monitoring program shows a stationary rate of seismicity since 1992, probably coupled to a stationary production rate. Based on this we present a first order site-specific hazard estimate using a Probablistic Seismic Hazard Analysis (PSHA). We predict, and observe, relatively high Peak Ground Accelerations (PGA). PGA above 0.2g is not unusual, but damage has so far been restricted to non-structural damage, mainly cracks in masonry. Relevant hazard estimates for the local, mostly low-rise buildings are given in terms of Peak Ground Velocity (PGV) or the maximum in the 50% damped response spectra at 10 Hz. For example, above the largest Dutch gas field, the Groningen field, we expect that peak values of 20 and 30 mm/sec may be exceeded with a 10% probability in one and 10 years, respectively. Above some small (about 3-4 km2) gas fields, Roswinkel and Bergermeer, we expect values around 35 and 60 mm/sec, respectively. These values, which exceed the Dutch building research (SBR) vibration guidelines, are obtained using simple model assumptions and are accompanied with an uncertainty analysis. The PSHA provides an important additional insight for the decision maker as to which relevant uncertainties may be decreased and which not. This can be and is being used to set research and monitoring priorities.

## SC-F 5-II: Seismic Hazard and Risk due to Induced Seismicity

Friday 13:30 - 15:00 – Room 18

### THE MW 4.4 ROTENBURG, NORTHERN GERMANY EARTHQUAKE AND ITS POSSIBLE RELATIONSHIP WITH GAS RECOVERY – ID 2051

*T. Dahm, Uni Hamburg, Germany*
*F. Krueger, Uni Potsdam, Germany*
*K. Stammler, BGR, Germany*
*K. Klinge, BGR, Germany*
*R. Kind, GFZ, Germany*
*K. Wylegalla, GFZ, Germany*
*J. R. Grasso, Grenoble, France*

We study the Mw 4.4 , 20th October 2004 Rotenburg (Wuemme) earthquake, located in a previously aseismic region in the Northern German sedimentary basin We constrain the source parameter by using different techniques. A possible relationship between this event, the regional tectonic setting and local gas recovery is investigated. Different waveform inversion and modeling approaches constrain the depth of the main shock between 5 and 7km. The source mechanism was oblique normal faulting on planes striking roughly NS. An inversion for kinematic rupture parameters indicates a unilateral rupture propagation towards the north, consistent with the higher macro-seismic intensities found towards the north in the region of Hamburg compared to those at a similar distance towards the south in the region of Hannover. Relocations of the main-shock and three of the largest aftershocks indicate that these events occurred within a few kilometers from three major gas fields and at depth close to gas production intervals. The comparison with the seismicity triggered in the Northern Netherlands by the depletions of similar gas reservoirs in a similar tectonic environment suggests that the M_W=4.4 Rotenburg event may be related to gas recovery.

### RISK OF INDUCED SEISMICITY IN GEOTHERMAL SYSTEMS AND POSSIBLE WAY FORWARD – ID 2053

*R. Baria, Mil-Tech UK, UK*
*E. Majer, LBNL, United States*
*M. Fehler, LANL, United States*
*N. Toksoz, MIT, United States*
*C. Bromley, IGNS, United States*
*D. Teza, BESTEC, Germany*

As the global demand for energy resources increases it is becoming apparent that geothermal energy and other resources of energy will play a significant part in meeting this demand. Exploitation of deep resources such as geothermal, mining, hydrocarbon etc. will need manipulation of the deep geological setting to release the economic resource. Seismic events may be generated during the extraction or the manipulation of the economic resource. One of the environmental as well as scientific issues that will need to be addressed is the effect and the role of induced seismicity in the management of these resources. The generation of felt (?) seismic events with a magnitude 2 and above may cause concern among the local residents. In particular, the general public's perception is that this induced seismicity may cause damage to structures on the surface, similar to that caused by "natural" earthquakes.

Enhanced Geothermal system has significantly more potential for delivering energy then a natural hydrothermal system, as the resource for this type of energy is significantly large. Generation of induced seismic events is a part of the development of this technology for reservoir development and the subsequent extraction of heat from underground. Some of these induced events have been large enough to be felt by populations living in the vicinity of current geothermal development sites. The objective is to investigate these events to obtain a better understanding of why they occur so that they can either be avoided or mitigated.

The IEA/GIA1 participants recognized this problem and therefore the topic of induced seismicity was added as one of the tasks in an Annex. The outcome of this was to hold workshops in February 2005 & 2006 after the reservoir-engineering meeting in Stanford. We summarise the ongoing work of this group here.

### CONTROL OF THE INDUCED SEISMIC HAZARD ASSOCIATED WITH THE HYDRAULIC STIMULATION OF A HOT FRACTURED ROCK GEOTHERMAL RESERVOIR – ID 1706

*S. Oates, Shell, Netherlands*
*J. Bommer, Imperial College, UK*

In 2003 hydraulic stimulations were carried out in El Salvador's Berlin geothermal field as part of a project to explore the feasibility of commercial hot fractured rock energy generation. A key requisite was that the induced seismicity associated with the reservoir stimulation at depths of 1–2 km should not produce levels of ground shaking at the surface that would present a threat or serious disturbance to those living in and around the field. A pump control system - which we refer to as the traffic light system - was implemented which utilised real time seismic monitoring data and ground motion estimates calibrated using accelerograph measurements. Thresholds of tolerable ground motion were inferred from guidelines and regulations on tolerable levels of vibration and from correlations between instrumental strong-motion parameters and intensity, considering the vulnerability of the exposed housing stock. These thresholds were defined in terms of peak ground velocity (PGV) and incorporated into the traffic light system through locally derived predictive equations for PGV in terms of event magnitude. The system also took into account the frequency of occurrence of the induced earthquakes. During the stimulation operations we encountered a much lower level of induced seismicity than anticipated such that the boundaries of the traffic light system were not tested but we argue that an approach such as this is a viable method for ensuring that hydraulic stimulation is conducted in an environmentally responsible manner. The major shortcoming of this type of approach is that it does not address the issue of seismicity occurring after the end of the pumping operation. This presentation is based on the material reported in detail in "Control of hazard due to seismicity induced by a hot fractured rock geothermal project", by Bommer, Oates, Cepeda, Lindholm, Bird, Torres, Marroquin and Rivas, to appear in Engineering Geology.

### MICROSEISMICITY INDUCED BY HYDRAULIC ACTIVITY IN A POPULATED REGION: CASE OF SOULTZ-SOUS-FORÊTS (NORTH ALSACE, FRANCE) – ID 1772

*J. Charléty, EOST-IPGS, France*
*L. Dorbath, IRD-LMTG, France*

Since 2000, four stimulations have been carried out at the geothermal site of Soultz-sous-Forêts (France). Each stimulation has induced a microseismic activity whose maximum magnitude is 2.9. Even if the magnitude was not large the project had to face some annoyance from the population, which is linked to the nuisance caused by the few largest earthquakes. Indeed the lowest magnitude felt in this particular area is 1.4.

In this work, we will present the induced seismicity caused by the hydraulic activity in terms of spatial and temporal distribution as well as in term of Gutemberg-Richter laws. We will also characterise the vibrations felt at the surface in a reference of levels for vibration perception of human sensitivity.

## SC-F 6-I: Geophysical and Civil Engineering Aspects of Hazard, Risk, and Mitigation for Major European Cities

Monday 13:30 - 15:00 – Room 15

### EARTHQUAKE MASTER PLAN FOR ISTANBUL – ID 1901

*A. Ansal, Bogazici Uni. Kandilli Obs & Earthquake Res. I, Turkey*

The Earthquake Master Plan for Istanbul has been motivated by the request of the Metropolitan Municipality to a consortium involving four leading Turkish universities. This commitment was fulfilled by the two teams, the first team is composed of researchers from Middle East and Istanbul Technical Universities, and the second team is composed of researchers from Bogazici and Yıldız Technical Universities. The main guiding principle has been the self-evident fact that while no natural disaster can be prevented from happening, the incorporation of well-formulated planning and technical counter-measures will mitigate damages and losses significantly. The scope of Earthquake Master Plan for Istanbul was composed of nine basic themes: (1) Assessment of current situation; (2) Seismic assessment and rehabilitation of existing buildings; (3) Urban planning issues; (4) Legal issues; (5) Financial issues; (6) Administrative Issues; (7) Earthquake information infrastructure; (8) Educational and Social issues; (9) Risk and disaster management issues. The major aim was to provide a short, medium and long term plan for the activities in these fields, preparation of implementation programs, and identification of the responsibilities and responsible authorities for earthquake disaster mitigation works to be carried out in Istanbul. The way the issues have been identified and solutions offered are likely to be different submitted by the two teams. This is natural because a comprehensive master plan is related in a complex way to legal, administrative, financial and social matters. Solutions in such contexts are not necessarily unique as in technical matters, and can reflect a multitude of syntheses leading to some different set of recommendations. The realization of the Master Plan can not be accomplished only within the province of the local government, but requires support and close cooperation of the parliament and the executive branch of government.

### EARTHQUAKE RISK ASSESSMENT FOR INDUSTRIAL FACILITIES IN THE ISTANBUL METROPOLITAN AREA – ID 2042

*E. Durukal, Bogazici University, Turkey*
*M. Erdik, Bogazici University, Turkey*
*E. Uckan, Bogazici University, Turkey*
*K. Sesetyan, Bogazici University, Turkey*
*M. Demircioglu, Bogazici University, Turkey*

In recent decades earthquake disaster risks to industry in urban centers of both developed and developing countries have increased. The increase in the developed countries is due to aging facilities, greater dependence on technology and simply, more values exposed to risk. Whereas in developing countries the main sources of the increased seismic risk can be attributed to faulty land-use planning, improper design and construction of industrial facilities and inadequate infrastructure and services.

Following the losses suffered during the two major earthquakes that struck Turkey in 1999, there has been a broad recognition among Turkey's governmental, non-governmental and academic organizations of the need for extensive response planning based on detailed risk analyses of likely seismic hazards in Turkey general and, Istanbul, in particular. One of the largest risks evidenced by the earthquake and partly assumed by the insurance sector has been associated with the industrial facilities.

The paper analyses the earthquake risk to the industrial under the following sections:

1.Damages to industrial facilities during past earthquakes 2.Inventory of industrial facilities 3.Definition of the most probable earthquake and associated hazards 4.Typification of the industrial facilities Identification of appropriate vulnerability relationships 5.Estimation of losses to industrial facilities.

The paper culminates with generic description of damage expected in industrial facilities depending on the earthquake intensity that they will be exposed in the case of the occurrence of the scenario earthquake. For the professional engineer, the study contains enough information and data to enable him/her to carry out a first order estimate of the specific earthquake risk to a given industrial facility.

### ESTIMATE OF FREQUENCY AND DAMPING FOR LARGE SETS OF BUILDINGS IN DENSE URBAN AREAS – ID 211

*M. Mucciarelli, Università della Basilicata, Italy*
*M. R. Gallipoli, Università della Basilicata, Italy*

The aim of the project NATO Science for Peace 980857 (ASSASBV) is to mitigate seismic risk in the cities of Skopje, Zagreb and Ljubljana. One of the tasks of the project is to perform estimates of the fundamental frequency of buildings and of underlying soils, in order to identify possible resonance phenomena. This resonance approach has been recently introduced for microzonation studies of large cities (e.g. Granada in Navarro et alii, 13th WCEE, 2004). Obtaining fundamental frequency and damping is the first step to validate vulnerability models of buildings. Standard and detailed approaches will be used for a limited number of selected buildings: the challenge faced in the ASSASBV project is to obtain simple but reliable estimates of dynamic parameters for thousands of building in a two-year time. This has to be achieved with the same instrumentation used on soils and without induced forcing. We propose a time-domain non-parametric method that does not require filtering and assumptions on signal structure, nor multiple measurement points or clear single transients induced by shakers, shocks or release test. This overcomes some of the disadvantages of well established approaches like RandomDec (Vandiver et alii, Journ.Mech.Des., 1982), half-power method (Clough and Penzien, 1975) or wavelet-logarithmic decrement or cross-correlation (Lamarque et alii, Journ.Sound.Vib, 2000). The analysis of a 10 minutes recording of ambient noise with a single high-resolution seismometer atop the building can provide a good estimate of the required parameters for the first two flexural modes. We checked the stability of the proposed method with respect of the duration of the signal and compared the results obtained by others with standard techniques. We explored also possible limitation due to building height and construction materials (reinforced concrete or masonry).

### AN ADVANCED APPROACH TO EARTHQUAKE RISK SCENARIOS OF SOFIA – ID 831

*A. Kaneva, CLSMEE, Bulgaria*
*M. Kostov, CLSMEE, Bulgaria*
*E. Vaseva, CLSMEE, Bulgaria*
*D. Stefanov, CLSMEE, Bulgaria*
*G. Varbanov, CLSMEE, Bulgaria*
*N. Koleva, CLSMEE, Bulgaria*

The assessment of the seismic risk is of special importance for the management of a capital large city. The resulting produced maps give pictures of the consequences of a possible earthquake to the city based on the research carried out and characteristic data collected in GIS format for the elements of a city, buildings, population, etc. It constructs earthquake-damage scenarios that serve to predict damage and undertake proper countermeasures to reduce the consequences. In this report is presented a short description of the research performed for the city of Sofia in the frames of the RISK-UE project "An advanced approach to earthquake risk scenarios with applications to different European towns" of the Fifth framework programme of EC. The assessment is achieved in the following basic steps: identify the building stock of Sofia; evaluate seismic hazard of Sofia; analyze Sofia urban system exposure; perform the vulnerability assessment of building stock and lifelines; evaluate the earthquake risk for Sofia and produce the maps of the consequences. All these steps are

discussed in the paper with the methodology explained briefly and results for each step. The discussed approach is applied to the city of Sofia in the frames of the RISK-UE project.

### EARTHQUAKE RISK RESEARCH IN ROMANIA - !0 YEARS OF COLLABORATIVE EFFORTS – ID 480

*F. Wenzel, Geophysical Institute, Germany*
*G. Schmitt, Geodetic Institute, Germany*

A Collaborative Research Centre 461 'Strong Earthquakes – From Geosciences to Civil Engineering' (http://www-sfb461.physik.uni-karlsruhe.de/) has been established in 1996 in response to the Kobe earthquake of January 17, 1995 that demonstrated the interdisciplinary needs of earth science and civil engineering. The Centre defined its regional focus in Romania, with Bucharest as the European city with the second highest risk after Istanbul. In addition to interdisciplinary work the cooperation with various Romanian institutions has high priority.

Key objectives of current research are: (1) Completion of methodology and data base for site-specific probabilistic hazard assessment and quantification of a geodynamic model of intermediate depth Vrancea earthquakes. (2) development of ground motion maps (Shakemaps) on urban and regional scale using neural net methods for the correlation of geological and seismological observations and considering liquefaction potential and other nonlinear soil behavior. Together with an improved Early Warning System key elements of an Earthquake Information System will be established. (3) Completion of the Disaster Management Tool (DMT) with additional modelling, decision support and communication components. It will become fully operational and will be tested in cooperation with the Romanian Civil Protection Command.

The presentation will give an overview on recent results and past achievements, such as: (1) The accelerometer installations in Bucharest, as well as the country-wide K2-network maintained by the National Institute of Earth Physics (NIEP) and INCERC and the data jointly exploited. (2) A seismic broadband experiment (Urban Seismology – URS) with 32 instruments for almost one year in operation in Bucharest was carried out with NIEP. (3) Geological and hydrogeological data were collected and documented with the Bucharest Metro Company METROUL and Bucharest University. (3) The DMT has been tested during an earthquake exercise in cooperation with the Civil Protection Command (ATLAS) in October 2004.

## SC-F 6-II: Geophysical and Civil Engineering Aspects of Hazard, Risk, and Mitigation for Major European Cities

Monday 15:30 - 17:00 – Room 15

### NATIONAL AND INTERNATIONAL EFFORTS FOR SEISMIC RISK MITIGATION IN BUCHAREST, ROMANIA – ID 995

*D. Lungu, UTCB/INCERC, Romania*
*C. Arion, NCSRR/UTCB, Romania*
*R. Vacareanu, UTCB/NCSRR, Romania*

The capital city of Romania is recognized as the European capital with the highest seismic risk. The high seismic risk is due to the combination of severe and very peculiar seismic hazard due to Vrancea subcustral seismic source located at about 100-150 km from the city (PGA $\geq$ 0.35 g for MRI = 475 yr. and long period of ground vibration, 1.5 s) with the existing fragile tall RC buildings in central Bucharest. The long predominant period of the ground motion observed during the strong Vrancea earthquakes of March 4, 1977 (moment magnitude Mw=7.5) and August 30, 1986 (Mw=7.2) was extremely aggressive for hundreds flexible tall RC structures built before the Second World War and even before 1977 event in city center. Romanian Government and local administration, as well as the technical and scientific community seriously focussed on the mitigation of seismic risk in the last 15 years. Romania is now the unique European country having a set of laws and regulations related to the identification of most risky buildings and to their retrofitting, including financial solutions for those operations. The paper presents the status of all actions related to building retrofitting in Bucharest, including the recently started World Bank Hazard Risk Mitigation and Emergency Preparedness Project in Romania (2004-2009) - Component B: Earthquake Risk Reduction. It also describes the synergy between national programs and international projects as: JICA Project "Seismic Risk Reduction for Building and Structures in Romania", RISK-UE Project "An advanced approach to earthquake risk scenarios with application to 7 European towns (2001-2004), SFB 461 Project"Strong Earthquakes: A Challenge for Geosciences and Civil Engineering" (1995-2007), NATO Project, Harmonization of Seismic Hazard and Risk reduction in Countries influenced by Vrancea earthquakes (2004-2007), European Project PROHITEC "Earthquake Protection of Historical Buildings by Reversible Mixed Technologies" (2007-2009) and others.

### SEISMIC FRAGILITY OF HIGH RISE RC MOMENT-RESISTANT FRAMES. ESTIMATION OF DRIFT HAZARD – ID 1000

*R. Vacareanu, UTCB/NCSRR, Romania*
*B. Chesca, NCSRR/UAUIM, Romania*
*P. Olteanu, Inginerie Civila SRL, Romania*

The estimation of structural performance under seismic loads, in particular the estimation of the mean annual rate of exceeding a specified level of structural demand, e.g., maximum peak interstorey drift ratio $\theta$max or a certain limit-state capacity is an important issue in Performance-Based Earthquake Engineering. The Incremental Dynamic Analysis (IDA) involves performing nonlinear dynamic analyses of the structural model under a suite of ground motion records, each scaled to several intensity levels designed to force the structure all the way from elastic behavior to final collapse state (Vamvatsikos and Cornell, 2002). Thus, one can generate IDA curves of the structural response, as measured by a Damage Measure (e.g., max. peak interstorey drift) versus the seismic intensity level, measured by an Intensity Measure (e.g., peak ground acceleration or the 5%-damped first-mode spectral acceleration Sa (T1;5%)). In turn these can be processed and summarized to get the distribution of demand Damage Measure given Intensity Measure. One can derive the mean annual frequency that the displacement-based demand (e.g., maximum peak interstorey drift) exceeds a given value d, also referred to as the "drift hazard (Jalayer and Cornell, 2003). To illustrate the methodology, it is used a high-rise RC moment-resisting frame structure designed according to the earthquake resistant codes in force in Romania. The seismic motion intensity measure as selected the peak ground acceleration (PGA). The seismic motions used during the analysis consist of nine classes of random proc-esses comprising ten samples each. Elastic ac-celeration spectra are used to generate samples. For parametric analysis purpose, the accelero-grams are artificially generated at predefined values of PGA. The computer program IDARC 2D (Kunnath et. al., 1992) is used for performing inelastic dynamic analy-ses.

### APPLICATION OF DATA DERIVED BY REMOTE SENSING FOR VULNERABILITY ASSESSMENT OF URBAN AREAS – ID 1412

*J. C. Münich, Universität Karlsruhe (TH), Germany*
*L. Stempniewski, Universität Karlsruhe, Germany*

Objective of this study is the research to enhance assessment methodologies for supply in a risk monitoring tool using data derived by satellite. The research area of this study is Zeytinburnu, a district of Istanbul. Zeytinburnu offers a wide spectrum of different typical building structures and was subject of numerous studies in the past. The ongoing urbanisation is accountable for the genesis of huge urban areas. Istanbul with an annual average

increase of 400,000 new inhabitants and with a supposed number of inhabitants of 14,000,000 is one of the so called Megacities. This fast growing population is responsible for the dynamic development in the building stock. Resulting rapid alteration necessitates the consideration of the changes in periodic time steps for the perpetual risk assessment analyses. Another aggravation is that many dwellings were build without considering legal norms, engineering knowledge and also without permission of the municipality, hence no development plan exists to show number of dwellings and properties. Respecting these circumstances a first stage assessment becomes important pointing out the areas with the highest risk levels. Accepted and well known methods take into account building parameters observed by street. Surveys require a tall assignment of human resources, especially for mapping the alteration. With the use of new technologies from the field of remote sensing, a fast and semi automatic method for a first stage risk assessment is possible and thus the necessary use of human resources and time decreases. Therefore building properties differentiable by air photographs are required. Vulnerability functions for different types of buildings must be developed which are able to take into account the discrepancies in the building classification methods. The risk assessment model is developed on the basis of the building distribution in Zeytinburnu and adjusted damage functions derived from the intensity based vulnerability functions of ATC.

### EARTHQUAKE RISK MAP OF EUROPE – ID 112

*P. Malhotra, FM Global, United States*

The geographical distribution of seismic risk is used for mitigation, pricing and transfer of earthquake-related risk. The building code maps do not provide a true picture of the seismic risk, because (1) building code maps do not make adjustments for local soil conditions, and (2) the return period of design ground motions in building codes is not uniform throughout the country. Seismic risk maps displaying the return period of damaging ground motions are generated as follows: (1) The firm-rock motions were obtained for 50-, 100-, 250- and 500-year return periods; (2) Free-surface motions were calculated by applying soil amplification factors to the firm-rock motions; and (3) Ground motion threshold for slight damage to poor buildings was applied to the free-surface motions to display the return period of nontrivial losses. Similar maps are being generated for the rest of the world.

### CHARACTERIZATION OF THE UNDERGROUND GEOLOGICAL SETTING OF FIRENZE (ITALY) FOR SEISMIC MICROZONATION STUDIES – ID 1865

*F. Agili, Earth Sciences Department - University of Firenze, Italy*
*V. D'Amico, Earth Sciences Department - University of Siena, Italy*
*G. Naso, National Civil Protection Department, Italy*
*N. Casagli, Earth Sciences Department - University of Firenze, Italy*
*D. Albarello, Earth Sciences Department - University of Siena, Italy*

Though the city of Firenze is located in a moderate seismicity area, the huge artistic and architectonic value of the elements exposed at risk along with their high vulnerability level makes the local seismic risk anything but negligible. Thus, studies devoted to the seismic microzonation of the city area could be particularly significant. An effort in such a direction is presented in this study. Starting from the analysis of about 1200 stratigraphic logs, an underground geological model is defined for the city, in which the distribution of the major sedimentary bodies (i.e. fluvio-lacustrine deposits) and the bedrock morphology are highlighted. By considering the thickness of soft sediments and information available from about 180 laboratory geotechnical tests and 20 down-hole/cross-hole tests, the study area is divided into a number of zones, where a nearly homogeneous seismic response could be expected. For each of these zones, amplification functions are then computed using a monodimensional code. Resulting values of soil fundamental resonance frequencies obtained from the numerical modelling generally agree with those assessed through a wide survey of seismic noise measurements analysed using the HVSR technique.

## SC-F 7: Potential for Very Large Earthquake Disasters in the European Mediterranean Region

Tuesday 10:45 - 12:15 – Room 7+8

### SOCIETY AND SEISMIC RISK – ID 1814

*L. A. Mendes-Victor, CERU, Portugal*

In a Rational speech, the incident report of a catastrophe proves that there is important missing in the cognitive world. The seismic accidents that take place at present demonstrate the lack of capacity of the individuals to apprehend the context of these environmental risks, where accidents should not take place. To what it seems to be lacking, in order to implement the society awareness of catastrophes, which are products of Risk, of its management and of an adequate strategy of prevention, should be the convenient understanding and perception of the way they are detected and located. . In spite of the existing stocktakings and of the better knowledge of social interactions in the modernity, the catastrophes keep on provoking large number of victims, especially due to the strategic incomprehension, shown also in the global society.

### LARGE EARTHQUAKES IN THE HELLENIC ARC AND TRENCH SYSTEM: PAST, PRESENT, FUTURE – ID 1995

*G. Papadopoulos, Institute of Geodynamics, National Observatory, Greece*
*A. Fokaefs, Institute of Geodynamics, National Observatory, Greece*
*K. Orfanogiannaki, Institute of Geodynamics, National Observatory, Greece*

The Hellenic Arc and Trench (HAT) system generates large instrumental earthquakes of M 7.5. Historical seismicity data indicate that earthquakes of M 8 also occur in HAT, like the earthquakes of 21 July 365 and 8 August 1303. They had very large areas of perceptibility and generated catastrophic tsunamis which propagated in remote places of the Mediterranean Sea. The similarity between the two events indicate that they constitute characteristic HAT earthquakes. However, the 365 earthquake ruptured the western segment while the 1303 earthquake ruptured the eastern segment of HAT. No other similar events are known to have taken place in the two segments of HAT. This implies that they are of very long return period. To investigate the present seismic status in the two segments of HAT we mapped the lateral distribution of rupture zones of (a) the two big earthquakes, (b) the large earthquakes (M over 7) of the last 400 yrs and (c) of the strong earthquakes (M over 6.5) of the last 100 yrs. It is observed that the rupture zones of the two big earthquakes were not ruptured by large earthquakes since about 1750 and by strong earthquakes since 1900 if not earlier. However, the areas that bound the two big rupture zones were ruptured up until 70's. These results may indicate that the areas ruptured by the 365 and 1303 earthquakes are strongly coupled failing to rupture by large earthquakes in last centuries, which may imply that big earthquakes are under preparation. The repeat of big events like those of 365 and 1303 in the future may cause dramatic consequences for many regions of the east Mediterranean Sea. Therefore, it is urgent need to study more systematically the western and eastern HAT segments but also to organize special countermeasures against future big earthquakes regardless the times they may occur.

### A UNIFIED DATABASE OF EUROPEAN EARTHQUAKES FEATURING LARGE EVENTS (UP TO M=8.5) – ID 1695

*G. Grünthal, GeoForschungsZentrum Potsdam, Germany*
*R. Wahlström, GeoForschungsZentrum Potsdam, Germany*

The study of the potential for large earthquake disasters, as well as other seismicity studies, require a high quality database. The catalogues from international seismological data centres, such as ISC, NEIC or EMSC and their predecessors, cover short time periods, and the Kárník "standard" catalogue for European and Mediterranean earthquakes, starting in 1800, has high strength thresholds. These sources do not meet the full requirements of many studies. The catalogue of European earthquakes presented here is based on domestic and regional earthquake catalogues of instrumental and historical earthquake data improved by numerous special studies on individual events or sets of events. It is the intention to include also paleoseismological data. Non-seismic (fake) events were identified and removed. Each event was assigned a unified magnitude, Mw, and, in the case of on-shore events, a maximum intensity. If not given by the original source, these measures were calculated by existing local transformation relations or by regression relations derived in the present study. The catalogue contains several earthquakes in the Mediterranean and the Atlantic Ocean areas with magnitudes of Mw=8 or larger. The potential for tsunami generation of such earthquakes in certain seismotectonic environments is large and disastrous events have occurred, e.g., Lisbon 1755 and Messina 1908. Also events down to Mw=7 and occasionally Mw=6 and smaller may pose severe consequences of human and structural damage whether a tsunami is generated or not. The distribution of the epicentres of large earthquakes, Mw=6 or more, shows a good agreement with the plate boundaries and their subsidiaries. Comparison is made with maps based on the ISC and Kárník data, which, although restricted in time, generally show larger scatter with respect to the plate boundaries.

### POTENTIAL FOR LARGE DESTRUCTIVE EARTHQUAKE IN WESTERN ALGERIA: PALEOSEISMOLOGICAL PERSPECTIVES – ID 56

*Y. Bouhadad, CGS, Algeria*

Paleoseismic investigations remain very limited in Algeria despite the relatively high seismic activity of the Tellean Atlas chain. Indeed, the only available studies are those performed in the El Asnam fault, following the October 10th, 1980 earthquake. Therefore, such data seem necessary to prevent any surprising major seismic event and to perform more realistic earthquake hazard models. Preliminary field investigations undertaken in western Algeria indicate very promising paleoseismic perspectives, particularly, in the southern edge of the Oran quaternary plain where one-meter vertical offset of quaternary deposits is observed along a characteristic fault scarp.

Key-word : Algeria- paleoseismic- perspectives- earthquake potential.

### A SEISMIC SOURCE MODEL FOR CENTRAL EUROPE AND ITALY – ID 2027

*M. Nyst, RMS, United States*
*C. Williams, RMS, United States*
*T. Onur, RMS, United States*

As part of an overall seismic risk and loss modeling project for Central Europe and Italy, we present a seismic source model for Central Europe (Belgium, Germany, Switzerland, and Austria) and Italy. Separate presentations at this conference discuss the different aspects of our project: ground motion modeling (Onur et al., 2006), vulnerability study (Baca et al., 2006), and probabilistic seismic hazard and risk assessment (Williams et al., 2006). Our seismic source model covers the whole region under consideration and consists of the following components: 1. A subduction zone environment in Calabria, SE Italy, with interface events between the Eurasian and African plates and intraslab events within the subducting slab. The subduction zone interface is parameterized as a set of dipping area sources that follow the geometry of the surface of the subducting plate, whereas intraslab events are modeled as plane sources at depth; 2. The main normal faults in the upper crust along the Apennines mountain range, in Calabria and Central Italy. Dipping faults and (sub-) vertical faults are parameterized as dipping plane and line sources, respectively; 3. The Rhine Graben (Roer Valley) system that runs from northern Italy into eastern Belgium, parameterized as a combination of dipping plane and line sources, and finally 4. Background seismicity, parameterized as area sources. The fault model is based on slip rates using characteristic recurrence; where applicable, time dependent assumptions have been included. The modeling of background and subduction zone seismicity is based on a compilation of several national and regional historic seismic catalogs using a Gutenberg-Richter recurrence model.

### COST-BENEFIT ANALYSIS OF INVESTMENTS IN PREPAREDNESS – ID 1926

*A. Smolka, Munich Reinsurance Company, Germany*

Billions of Euros are raised routinely after great natural catastrophes for disaster recovery and rehabilitation. Investments in proactive preparedness and prevention, however, represent only a small fraction of the amounts spent for retroactive disaster recovery. Cost-benefit analysis of efforts directed at prevention is an important means to convince decision-makers and the public to invest more in proactive disaster risk management practices. But performing such analyses is challenging: Whereas costs can be easily identified, the corresponding benefits are difficult to measure and uncertain, all the more as these benefits are not only savings in monetary disaster costs, but also – and most importantly – saved lives. Nevertheless such analyses have been carried out for various projects and programs, e.g. by the Federal Emergency Management Agency of of the USA and by the World Bank, and have proven a minimum monetary cost-benefit ratio of 1:4. Systematic comparative evaluations of cost-benefit ratios for various preparedness and prevention activities such as public education, land use planning, improved construction techniques and early warning systems are not common practice, but would be highly suitable for prioritizing and maximizing the use of available resources. In modern society there is a tendency to prefer expansive technological solutions against "soft" measures like education and awareness campaigns, a tendency which may not always be justified by cost-benefit considerations.

## SC-F 8-I: Near Real-Time Damage and Loss Assessment due to Strong Earthquakes

Wednesday 10:45 - 12:15 – Room 3

### VULNERABILITY FUNCTIONS FOR NEAR REAL-TIME DAMAGE AND LOSS ASSESSMENT: RISK-UE CONTRIBUTION – ID 2066

*Z. Milutinovic, IZIIS-Skopje, Macedonia*

The recent earthquakes in Europe and Mediterranean (Turkey, 1998; Greece, 1998; Italy, 2002; Algiers, 2003; Morocco, 2004) demonstrated that decision makers and disaster managers of earthquake-prone cities need concrete and reliable near real-time estimates on possible impacts of potential seismic events. Recognizing these needs ten European teams from seven EU and non-EU countries including local governments from seven selected cities have combined their knowledge on the earthquake phenomenon and its effects on buildings and population and in the context of the 5th European Commission Framework Programme lounged and completed a project "An advanced approach to earthquake risk scenarios, with applications to different European towns – RISK UE". Over the period of 3 years (2001-2004) RISK-UE has been concentrated on development of general and modular methodology for formulating earthquake-risk scenarios that concentrates on the distinctive features of European towns. RISK-UE Working Package 4 "Vulnerability Assessment of Current Buildings" has been focused on developing two level approach for assessing the vulnerability

of building typology used in current urbanization, i.e.: Level I, using traditional, so-called "macroseismic" or "statistic", methods based on a large damage data sets compiled in past earthquakes affecting Italy, Greece, Romania and former Yugoslavia, and Level II, using modern, so-called "mechanical (analytical)" methods, based on behavioral analyses, so-called "displacement analyses" for assessment of destructive "performance" and whose main development was proposed in the ATC 40 (1996) and the HAZUS (1999) project. The WP04 developments are principally carried out by IZIIS (Skopje), UNIGE (Genoa), AUTh (Thessaloniki), and UTCB (Bucharest) for a fundamentally European buildings' context, based on the typologies defined under the RISK-UE WP01. The presentation intends to discuss the achievements of RISK-UE, in particular Level I and II vulnerability functions developed for European building environment that can readily be implemented for real time apriori and all level (local, regional, global) damage/loss assessments.

### VULNERABILITY OF THE BUILDING STOCK ACCORDING THE EMS-98 - APPLICATION TO SOFIA – ID 409

*E. Vaseva, CLSMEE-BAS, Bulgaria*
*D. Stefanov, CLSMEE-BAS, Bulgaria*
*M. Kostov, CLSMEE-BAS, Bulgaria*
*A. Kaneva, CLSMEE-BAS, Bulgaria*
*G. Varbanov, CLSMEE-BAS, Bulgaria*
*N. Koleva, CLSMEE-BAS, Bulgaria*

Methodology for evaluation of vulnerability of buildings in a given region in terms of assignment of the vulnerability classes according the new EMS 98 scale is presented. The methodology is applied for vulnerability analysis on surveyed buildings in Sofia – Triaditca region. The main results of this case study are the graphs where are shown the distribution of buildings in different vulnerability classes; the relationships between different damage grades and intensity for some of the vulnerability classes. All results are presented in GIS format. The vulnerability curves are shown for types of buildings included in data bank of buildings, typical to Bulgaria. The results in this paper are received with financial support of European Commision in the frame of Project RISK-UE "An advanced approach to earthquake risk scenarios with applications to different European towns".

### BUILDING STOCK VULNERABILITY MODELLING FOR EARTHQUAKE DAMAGE AND LOSS ASSESSMENT – ID 2054

*S. Tyagunov, University of Karlsruhe, Germany*
*L. Stempniewski, University of Karlsruhe, Germany*
*G. Grünthal, GeoForschungsZentrum, Germany*
*R. Wahlström, GeoForschungsZentrum, Germany*
*J. Zschau, GeoForschungsZentrum, Germany*

Seismic vulnerability is one of the key factors determining the level of risk in earthquake prone regions. The vulnerability may affect different aspects of community safety (structural, functional, social, economic, etc.), though, primarily, the seismic vulnerability is considered in the structural sense, which implies the ability of buildings and structures to withstand seismic loads. Often the structural vulnerability of existing built environment might be responsible for the bulk of human and economic losses resulting from earthquakes. The paper presents a methodology of analysis and modelling of seismic vulnerability of the building stock of communities for damage and losses assessments on a regional scale. In the frame of the large-scale approach the main attention is paid to the seismic performance of the whole building stock of communities rather than to the seismic response of single buildings. Therefore, the principal core of the methodology is modelling of the vulnerability composition of the existing building stock of communities, which is implemented in terms of the vulnerability classification of the European Macroseismic Scale (EMS-98). Description and application of the methodology is given with specific reference to the residential building stock of earthquake prone communities of Germany. The vulnerability composition models are constructed on the basis of information derived from field observations and available databases. Validation and calibration of the models are performed with the use of observed data from a few past damaging earthquakes in Germany and the nearby area. The results of the validation prove that the developed models are adequate to predict the performance of the building stock under seismic influence and therefore they are applicable both for risk assessment studies and near-real time damage and loss estimates in the region.

### REAL-TIME ASSESSMENT OF EARTHQUAKE INDUCED DAMAGE: LESSONS LEARNED IN ICELAND – ID 1346

*R. Sigbjornsson, University of Iceland, Iceland*

This paper describes lessons learned in Iceland on near real-time assessment of earthquake induced damage. The scenario is the South-Iceland Lowland in June 2000, which has been hit by a devastating South-Iceland Earthquake leaving thousands of damaged buildings in its wake. The assessment of the damage had to be carried out swiftly, without any delays, to prevent people from staying in unsafe buildings as the area was being shaken by further on-going earthquakes activity. Furthermore, to provide the authorities with real-time information required for efficient planning of urgently needed relieve operation. The damage assessment and the subsequent numerical analysis was organised by the local Office of Building Inspector. The methodology adopted can be described as a 'real-time' on-line loss-estimation applying geographic information technology and the Internet. Information on damage was collected in the field by qualified engineers. This information was then transferred to a database already containing building related information like architectural and engineering drawings. This data was readily linked to the official real-estate database to get information related to each building, including insurance, value, number of inhabitants, their age etc. Furthermore, the databank was also linked to the Icelandic Strong-Motion Network, which provided real-time information on recorded ground motion. The data on damage, along with above mentioned information, could then be visualised, inspected and analysed using a password-protected Website. This Website provided the local authorities with a valuable analysis tool they could use to follow directly, from one hour to the next, the development in the field. Furthermore, they got a rapid estimate on extend and nature of the damage which proved helpful both in their short- and long-term planning of mitigating actions and relief operations. Finally, new development of this damage assessment system, introduced since the described real-time operation was carried out, is outlined.

### AUTOMATED DAMAGE DETECTION OF BUILDINGS FROM HIGH-RESOLUTION SATELLITE IMAGES – ID 714

*F. Yamazaki, Chiba University, Japan*
*K. Kouchi, University of Tokyo, Japan*

In the recent years, satellite remote sensing has become one of the most important and efficient tools to identify affected areas due to natural disasters, notably earthquakes, tsunamis, hurricanes, and floods. Among various remote sensing technologies, high-resolution optical satellites, e.g. QuickBird (QB) and Ikonos, have demonstrated their capability to capture damage distribution in urban areas due to disasters. Using actual high-resolution images with spatial resolution of 0.6-1.0 m, visual damage inspections have been conducted by several research groups for recent disasters. But it is time consuming to cover large areas and the results of visual inspection are dependent on interpreters. Hence in this study, automated damage detection methods are developed and their accuracy is examined, compared with the results of visual interpretation. As an example, QuickBird images obtained both before and after the 21 May 2003 Boumerdes, Algeria, Earthquake are employed. Both pixel based classification and object-oriented classification methods are used to identify severely damaged or collapsed buildings, which are characterized by debris around them. Based on pixel based classification using edge information,

commission errors are found to be significant because some vegetation and small objects have similar edge characteristics with debris. To reduce this error, confining search areas only around buildings is found to be efficient. On this purpose, object-based classification for the pre-event image is carried out to identify buildings automatically. Removal of vegetation based on the normalized difference vegetation Index (NDVI) is also recommended as pre-processing. Either object-based classification or spatial filtering is necessary to eliminate salt-and-pepper noises, which are interpreted mistakenly as debris. Following this procedure, automated damage detection using high-resolution optical satellites images is proven to be a very promising approach.

## SC-F 8-II: Near Real-Time Damage and Loss Assessment due to Strong Earthquakes

Wednesday 13:30 - 15:00 – Room 3

### PROMPT ASSESSMENT OF GLOBAL EARTHQUAKES FOR RESPONSE (PAGER): A SYSTEM TO ESTIMATE IMPACT FOLLOWING SIGNIFICANT EARTHQUAKES WORLDWIDE – ID 1782

*P. Earle, USGS, United States*
*D. Wald, USGS, United States*
*K. W. Lin, USGS, United States*

The US Geological Survey's National Earthquake Information Center (USGS/NEIC), with support from the US Agency for International Development (USAID), has implemented a system known as the Prompt Assessment of Global Earthquakes for Response (PAGER), which estimates the number of people exposed to severe ground shaking following significant earthquakes worldwide. PAGER obtains these estimates by combining maps of shaking intensity derived using a global version of ShakeMap with a global population database (Landscan2004) developed by Oak Ridge National Laboratory. PAGER's automatic analysis is finished within minutes following the release of a reviewed NEIC earthquake location and magnitude, and alerts are distributed via e-mail and text message. Impact reports with supporting ShakeMaps and population maps are posted on the Internet and distributed as RSS feeds.

Enhancements to PAGER are focused both on improved hazards estimation and loss quantification. In the hazard arena, we are working on producing better-constrained global estimated ShakeMaps with rapid finite-fault analyses (from both rapid aftershock analyses and seismic inversions), observed intensity and ground motion constraints, and regional ground motion prediction equations and site conditions. We are also adding in estimates of shaking-induced landslide probabilities. In the loss arena, we are pursuing two parallel and complementary tracks to loss estimation. For regions with quantifiable structural inventories, including the United States, we will use an analytical approach based on known building inventory and vulnerability to ground shaking. Loss estimates will be obtained from pre-computed loss versus ground-shaking tables (vulnerability tables) derived using FEMA's HAZUS methodology. In contrast, in areas of the world where detailed building inventories are not available, we will use empirical methods. We are developing regional vulnerability functions around the globe based on a region's performance during past earthquakes or from expert opinion in areas that have not experienced recent significant earthquakes.

### NEW GENERATION CODES FOR SEISMIC SCENARIO EVALUATION SUPPORTING EMERGENCY PLANNING AND MANAGEMENT – ID 1045

*F. Papa, Department of Civil Protection, Italy*
*R. Ferlito, Department of Civil Protection, Italy*
*A. G. Pizza, Department of Civil Protection, Italy*
*P. Soddu, Department of Civil Protection, Italy*
*F. Sabetta, Department of Civil Protection, Italy*

The main objectives of earthquake scenario analysis for Civil Protection are: a) after a destructive earthquake, providing a rapid approximate estimate of the damage, to be used for managing the emergency phase; b) at times of seismic quiescence, evaluating the impact of hypothetical but typical events in a region, in support of disaster relief planning. Since 1995, a computer program for seismic scenario analysis has been operational at the Italian National Seismic Service of the Civil Protection Department. The program is running on the Emergency Management Informative System and is used after any event in the national territory capable of producing significant damage. Earthquake consequences such as the expected number of damaged, unusable and collapsed dwellings; the direct economic losses; and the number of homeless individuals, casualties and fatalities in each municipality, are estimated in quasi real time. The performance in terms of global losses is generally satisfactory. However, the code has undergone various modifications and extensions to remove limitations and improve the accuracy of the original model. The first update of the program is the FACES code, which allows to consider linear sources, directivity effects, and the influence of focal depth. The most recent modification of the code is the development of a probabilistic analysis code called ESPAS that addresses to: quantify uncertainty on the many parameters and variables used in scenario analyses; update the initial post-event loss estimates using observed earthquake effects to provide more accurate evaluations as time goes by and more data become available. The paper describes the main features of the scenario methodologies mentioned above. Moreover it shows the results of several test either in terms of comparison among the different methodologies, or specifically on the results of the ESPAS code, through different application to real past events.

### PROPOSAL OF A SIMPLE SEISMIC EARLY WARNING SYSTEM FOR ALGERIA – ID 204

*M. Belazougui, CGS, Algeria*

Algeria is periodically stricken by seismic events that could trigger important human and material losses such as the "21st May, 2003 Boumerdes Earthquake" which resulted in very important losses ( 2300 dead people and 3 billions US$).

In addition to traditional countermeasures for seismic risk reduction, it appears for us of great importance to set up and implement an early (rapid) warning system for the case of damaging earthquake striking in the seismic prone areas of the country. It is expected from such a system to help for mobilizing very quickly the adapted relief and rescue means at local , regional and national levels, so that the human losses could be reduced and the recovery accelerated in the region hit by an earthquake.

In this system, 3 warning levels dealing with local, regional and national mobilizations are respectively proposed; they depend only on 2 parameters, population density representing the potential vulnerability in the epicentral region and its surroundings and the level of magnitude. they are inferred from a matrix with 4 entrances for ranges of population densities and 4 entrances for ranges of magnitudes.To illustrate the system, maps of warning levels are presented, for 4 ranges of magnitudes. Naturally the system has to be completed by more precise geodetic coordinates and a computerized model that could give automatically the level of warning immediately after the national seismological observatory give the main and necessary parameters of the warning: date, time, magnitude and geodetic coordinates of the epicenter.

The system can be improved later by introducing new parameters of influence as the deepness of hypocenter or the variability of regional vulnerability and periodically updated.

### STUDY OF EARTHQUAKE DISASTER ASSESSMENT FOR A LARGER AREA BASED ON GEOGRAPHIC GRID – ID 1640

*S. Xianghua, China Earthquake Networks Center, China*
*J. Lixin, China Earthquake Networks Center, China*

Taking the mainland of China as an example, this paper aims to introduce the approach to evaluate the disaster of earthquake. The approach is developed mainly based on geographic grid, and it is more effective when being applied to a larger area. In terms of the differences of various factors of building structure, site, population distribution and economic development, the mainland of China is divided into six sub-areas. Then we make a further study of every sub-area one by one, such as calculating vulnerability of buildings, determining seismic intensity attenuation and figuring out population distribution. And next, we divide averagely the whole mainland into 1km*1km grids. One gird is the minimum calculating unit in this approach. Taking the population, economy and building factors into account, we can work out the damages and losses of every grid and, finally, we can get the accurate distribution of the disaster. This approach will be very helpful to earthquake disaster emergency planning.

### DIFFERENTIATION OF DAMAGE FUNCTIONS ACCORDING THE NUMBER OF STORIES BY THE EQUIVALENT RESPONSE VALUE – ID 456

*M. Raschke, Co. M. Raschke, Germany*

In earthquake risk analysis, the relation between the local quake intensity and the local quake damage is calculated by damage functions, the damage being described as monetary or physical damage. This paper deals with the physical nature of damage as it is described by the damage classes of makroseismic intensity scales. The damage functions show the relation between the building stock´s proportions of the damage classes and the quantity of the local earthquake shaking. Here, this relation is reduced to the functions ´mean damage – quantity of shaking´ and ´dispersion – mean´. Only the function of the mean damage is a damage function itself and subject of this paper. The damage functions are differentiated according to building type here. The aim is a further differentiation of them according to the number of stories. In literature, this is mostly carried out on the basis of theoretical analyses and in the form of classes of storie numbers only. An individual damage function for each storie class is given there. Here, the equivalent response value is introduced and used for the differentiation of the damage functions according to the number of stories. The basic idea of the equivalent response value consists in the modification of the relation of the pseudo response values. The connection to the storie number is made by the relation ´number of stories – own period of buildings´ as usual. In this paper, this relation is discussed theoretically. The practicability of the approach is verified on the basis of theoretical damage functions. Then, an intensity based damage function for storey buildings made of reinforced concrete considering the number of stories is determined by the analysis of empirical damage data. Response spectra related to the intensity are used to solve this problem. The results are discussed.

## SC-F 8-III: Near Real-Time Damage and Loss Assessment due to Strong Earthquakes

Wednesday 15:30 - 16:30 – Room 3

### EXPECTED DAMAGE AND LOSS ASSESSMENT IN "EMERGENCY" MODE AT GLOBAL SCALE: ANALYSIS OF UNCERTAINTIES – ID 1264

*N. Frolova, Seismological Center of IGE, RAS, Russian Federation*
*V. Larionov, Extreme Situations Research Center, Russian Federation*
*J. Bonnin, Institute of Physics of the Earth, France*

The experience of recent disasters in many countries shows that the officials who are responsible for emergency response are lacking prompt and reliable information on the disaster scale. Nevertheless, timely and correct action just after an event can result in significant benefits in saving lives. In this case the information about possible damage and expected number of casualties is very critical for taking decision about search and rescue operations, as well as offering humanitarian assistance. Such information may be provided by near real time systems.

The paper addresses one of the questions most frequently raised by risk managers: what is the likely outcome (consequences) of a strong earthquake just occurred. It suggests procedures for estimating the potential impact of the event in terms of life and property losses. The procedures are based on a chain of models tackling seismic hazard, vulnerability of elements at risk, impact on population and goods. To start with, the earthquake source parameters are taken from specialized Agencies broadcasting rapidly determined event parameters. With these input data a probable impact is estimated and mapped, checked by experts against available previous macroseismic data and against early field observations, if applicable.

The reliability of expected damage and loss estimations with simulation models application strongly depends on uncertainties of information on elements at risk and hazard sources, that of regional vulnerability functions, as well as on discrepancies in strong earthquakes' parameters determination by different Alert Seismological Surveys.

The paper analyzes the influence of mentioned uncertainties, as well as that of intrinsic methods applied, on the reliability of estimations obtained with near real time systems application. The ways to increase the reliability of estimations in "emergency" mode and the efficiency of such systems are discussed.

### RAPID ESTIMATION OF MACROSEISMIC EFFECTS AND SHAKEMAPS USING MACROSEISMIC DATA – ID 1353

*P. Kästli, Swiss Seismological Service, Switzerland*
*D. Fäh, Swiss Seismological Service, Switzerland*

A quasi real-time estimation of earthquake effects has to rely on recorded ground-motion data that are available before damage information is arriving from the affected areas. Macroseismic intensity is thus estimated from the online seismic data stream, generally with a single parameter describing the ground motion. Since macroseismic intensity scales are based on descriptions of various types of earthquake effects, the performance of instrumental-parameter to intensity conversions is limited.

We use a set of pairs of instrumental measurements and intensity assessments from the same event and site to derive empirical relationships between macroseismic intensity and instrumental parameters such as PGA, PGV, Arias Intensity, and Housner Intensity. Empirically derived probability models allow to estimate intensity from instrumental data, and vice versa. The performance of these probability models varies for different intensities: While low intensity levels II to IV are more precisely estimated from PGA, PGV-based models perform best to distinguish damaging shaking from non-damaging shaking. The derived probability models are compared to other published intensity ground-motion relations.

One application of this ground motion-to-intensity conversion is a tool developed at the Swiss Seismological Service which uses waveforms from online seismometers to calculate intensity-based shakemaps for Switzerland within some seconds after an event. These instrumental shakemaps are counterchecked by shakemaps derived from automatical processing of internet-based macorseismic questionnaires. This combination helps to improve the quality of information within the first minutes after a strong earthquake.

Predicting earthquake effects for places without seismic instruments needs profound knowledge of the local site condition and related site amplification effects. In regions with heterogeneous subsoil conditions as for example in Switzerland, site effects estimations relying only on the top soil conditions provide only limited information. We therefore present a case study for Switzerland, and discuss the possibility and limits of simplified methods for site-effect estimations.

### COMPARATIVE ANALYSIS BETWEEN EARTHQUAKES, TSUNAMIS AND OTHER NATURAL HAZARDS – ID 1241

*B. Ranguelov, Geophysical Institute, Bulgaria*

The different natural hazards have different destructive potential (here defined as volumes or masses involved in the movements and/or their velocity/energy of the natural process). According to the physical properties of the medium (air, water or solid Earth masses movements or energy – elastic, heat, freeze, etc.) the natural limitations of the consequences they can created are usually observed. All natural phenomena (appearing hazards like anomalies in their effects) have different measuring scales – magnitude, intensity, etc. according their power expression. Frequently the size of the affected area depends of the power of the natural hazardous event. Some of the hazards have only local influence (tornado, avalanches, etc...), some can cover larger areas depending on their magnitudes (earthquakes, tsunamis, volcanoes, etc.) and some have even global effects (El Nino, ozone hole, global warming). Summarizing the similarity of the effects, which the different natural hazards can produce and using different physical parameters for arrangement, several classifications have been created about: - area coverage (based on the destructive potential) - time duration (based on the velocity and the power of the hazards) - possibilities of the early warning (based on the sudden appearance and predictability) All these classifications can serve about the estimation of the affected structures (their numbers, domino effects, etc.), secondary effects they could create and the possible preventive measures about the safety of the structures. The comparison between the earthquakes, tsunamis and other natural hazards has been done on the bases of the above mentioned classifications. The results obtained could be useful for the implementation in the near real time damage and loss assessment systems.

## SC-G 1 & SC-F WG: National Methodologies for Macroseismic Field Surveys (Joint Session with SC-F WG on Macroseismology)

Thursday 17:15 - 18:15 – Room 7+8

### MACROSEISMIC FIELD SURVEYS IN ITALY: THE ORGANISATION OF THE ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA (INGV) – ID 1941

*R. Azzaro, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*R. Camassi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Tertulliani, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

Since 2001 the INGV has been carrying out, under the umbrella of the internal working group QUEST (Quick Earthquake Survey Team), activities aimed at investigating earthquake effects. The team consists of some twenty people that alternatively participate in the surveys, depending on the earthquake size, its epicentral location and staff availability. The distribution of the INGV departments throughout the Italian territory makes it possible to intervene not only in case of severe earthquakes, but also for moderate events. Each local group (i.e. Catania for Sicily-Calabria, Rome for Central Apennines, etc) is responsible and "guardian" for the part of Italy falling within its range of action. Our "reaction time" for Italian earthquakes is very fast: alerted by SMS from the INGV automatic location system of the national seismic network, we are able to organize a preliminary survey in the following three-four hours. Macroseismic investigations are generally carried out according to a standard protocol in order to obtain homogeneous data: direct field observations in the damaged area, telephone surveys in the far field, collection of macroseismic data for applying MCS and EMS intensity scales. In the period 2002-2005, QUEST has conducted 8 reconnaissance surveys for (fortunately) moderate events. During the emergency the field teams, occasionally flanked by other personnel from universities etc, are coordinated by a central bureau that updates the intensity map in real time, maintains contact with the Civil Protection authorities and disseminates (if possible) the collected data by internet. The last experience of QUEST was the participation at EUROSOT 2005, an international training operation of a simulated earthquake occurring in Eastern Sicily, during which the INGV team checked its coordination and communication system in field activities.

### METHODOLOGY FOR MACROSEISMIC FIELD SURVEYS IN SLOVENIA – ID 1659

*I. Cecic, ARSO, Slovenia*

As the history of macroseismic surveys in Slovenia lasts for more than 100 years, only the most recent example of methodology for macroseismic fiels surveys will be discussed. Due to the moderate seismicity of the region, the damaging earthquakes do not happen often in Slovenia, so there is no such thing as a permanent field team. In a case of a damaging earthquake (intensity larger than V EMS-98), and considering the degree of damage and the size of the affected area, one or more field teams are formed. The main team consists of a senior seismologist and a civil engineer, and the other teams are formed depending on the situation in field. In case that the most affected area is not too large, the teams tend to inspect every building and collect as many data as possible, including the photographic evidence. During their work, some previously prepared forms are used, making the data collection easier and more efficient. The field work may last from one to several days, depending on the size of the area and the intensity of the main shock, as well as of the number of strong aftershocks. The main tool for data evaluation is EMS-98. In the second step, the data obtained by our teams are combined by the data collected by the official commissions for damage evaluation.

### A MODEL FOR SEISMIC DAMAGE, VULNERABILITY AND SAFETY EVALUATION OF STRUCTURES: MEDEA – ID 1130

*F. Papa, Dip. della Protezione Civile, Uff. Serv. Sismico, Italy*
*G. Zuccaro, Centro Studi PLINIVS - Universtity of Naples, Italy*

The paper presents a methodology for quick evaluation of vulnerability and seismic damage, based on a selftraining multimedia handbook called MEDEA. In its first application MEDEA was designed as a protocol to collect seismic damage interpreted in terms of collapse mechanisms, in order to support traditional tools for safety survey nowadays used in Italy, in which the description of the damage is performed only through the analysis of the extension and the damage level. Two Multimedial CD Rom (masonry and reinforced concrete) have been realized, able to address the technicians involved in survey teams for damage and safety evaluation. The software presented offers interesting cues for an 'objective' evaluation of such data. In its original idea MEDEA was proposed as: a) a handbook for a consistent categorization of the structural elements in masonry and r.c. buildings and of their relevant damage typologies; b) a teaching tool for the training of technicians involved in damage and safety evaluations in postearthquake management; c) a supporting tool for a more detailed safety survey form; d) a guided tool for macroseismic evaluation on the field; e) a teaching resource to be used at different levels. In a second step MEDEA has became a tool to be used also during the "peace time" for the analysis of structural typological characteristics, interpreted as structural deficiencies able to influence the seismic behaviour, addressing towards preferential collapse mechanisms. On this base, a specific survey form, called MEDEA, has been designed, in order to analyze the relationships among collapse mechanisms, different seismic damage and vulnerability factors of the building. Therefore the paper outlines a simple procedure for a numeric evaluation of the damage and the seriousness level of the possible collapse mechanisms, that represents a first attempt to measure the residual capacity of the building.

### USING THE NEW INQUA INTENSITY SCALE FOR THE INTENSITY ASSESSMENT OF GREEK EARTHQUAKES – ID 324

*A. Fokaefs, National Observatory of Athens, Greece*
*G. Papadopoulos, National Observatory of Athens, Greece*

The new INQUA seismic intensity scale is an important challenge in the fields of macroseismology and earthquake geology. In order to calibrate the scale, compare it with conventional scales and improve it, we have selected three strong Greek earthquakes for which the observational material is reliable and detailed enough and, therefore, provides a good basis to test the new INQUA seismic intensity scale. The earthquakes selected are the following: Kyllini, NW Peloponnese, 16 October 1988 (Ms = 5.8), Athens, Attika, 7 September 1999 (Ms = 5.9), Lefkada island, Ionian Sea, 14 August 2003 (Ms= 6.3). These earthquakes were strong and their macroseismic effects included not only damage in buildings and other structures but also environmental effects like ground failures of several types like local landslides, rock-falls, ground fissures and soil liquefaction, which are taken into consideration by the new Inqua Scale. In addition, the macroseismic fields of the selected earthquakes were studied and intensities in conventional scales were assessed during post-event field surveys undertaken by the authors. A comparison between the conventional and new intensities has been made and the results are evaluated as regards the efficiency and possible future improvement of the new INQUA scale.

## SC-G 2: Recent Macroseismic Field Surveys

Thursday 15:30 - 16:45 – Room 7+8

### COMPARISON TEST OF THE MOST COMMONLY USED BIVARIATE INTERPOLATION ALGORITHMS (TO DRAW ISOSEISMALS) – ID 618

*F. Pettenati, Istituto Nazionale O.G.S., Italy*
*P. Galuppo, Paneura Software & Services, Italy*
*B. Vladan, Paneura Software & Services, Italy*
*L. Sirovich, Istituto Nazionale O.G.S., Italy*
*M. Bobbio, Istituto Nazionale O.G.S., Italy*

We tested some of the most common bivariate interpolators, which are used to compute isolines of many kinds of data. It must be remembered that different contours are needed to show data (without filters), and, on the other hand, to interpret various fields and to forecast resulting data in unsampled points. In particular, we faced the problem of drawing isoseismals, and so considered the following approaches: Kriging (B.S.S.A., 95, pp.540-548), Spline in Tension (extremes harmonic and bi-harmonic cases: tension equal 0.2 and 0.8 respectively) (B.S.S.A., 92, 6, pp. 2061-2079), Invers Weighted Distance Averages (IWDA, Comput. Geosci., 15, 79-94), and our natural-neighbor application (N-N) (B.S.S.A., 92, pp.1933-1940). For this, 267 sparse locations were considered (from an earthquake of 1936 in NE Italy). Firstly, N-N was confirmed to be the best pre-processing for sparse data, to obtain easy-to-grasp pictures and to find outliers and errors. Secondly, we produced a 267 synthetic data set by the Grandori et al. (1987) attenuation; then, we trimmed it by 30 data points chosen by random and, again, by 26 data points only in the epicentral area (where the Grandori et al. relation produces a plateau). Then, we used all interpolators (with two sets of contouring parametres [note that N-N is parametre free]), and calculated the RMS errors (calculated-minus-observed in the trimmed sites). N-N was best at catching the Grandori plateau well (with harmonic Spline, T=0.8, as silver medal); bi-harmonic Spline, T=0.2, won the 30-trimmed test over the N-N interpolator. Thirdly, we repeated the test of B.S.S.A., 92, pp.1933-1940 (Fig. 6; 38 171-data sets, two outliers included, randomly trimmed by 7 intensities). The RMS errors and the Chi-squares were calculated on the 38 trimmed sets (with the observed intensities as reference). In this test, Kriging won gold, and N-N silver.

### SPATIAL DAMAGE DISTRIBUTION AND SEISMOLOGICAL ASPECTS OF THE 2003 NOVI L. (ITALY) MW=4.9 EARTHQUAKE – ID 960

*S. Podestà, Dept. of Structural and Geotechnical Engineering, Italy*
*S. Resemini, Dept. of Structural and Geotechnical Engineering, Italy*
*D. Bindi, National Institute for Geophysics & Volcanolog, Italy*
*D. Spallarossa, Dept of the Study of the Territory & its Resou, Italy*
*F. Pacor, National Institute for Geophysics & Volcanolog, Italy*

On April 11 2003 a Mw=4.9 earthquake occurred in North Western Italy. The macroseismic aspects, concerning the structural damage, were investigated throughout the damage and safety assessment after the seismic event, coordinated by the Piedmont regional administration. This survey involved more than 5000 buildings. In particular, 270 monumental buildings (churches) were investigated through a twofold survey methodology: the ministerial inspection form (PCM-DPC 3-5-2001 Ministry Decree) has been filled together with the new 28 damage mechanisms form, proposed after 2002 Molise earthquake (Southern Italy) and recently adopted as official form for the damage survey section. This survey methodology is suitable to achieve not only damage distribution information, but also data about structural vulnerability: deep technological investigations and observational data of the slight/moderate seismic damage were adopted to explain the activation of several damage mechanisms. The collected data were used to build up the preliminary seismic damage scenario. The presence of damaged buildings concentrated in specific azimuthal sectors is not completely explainable with the structural intrinsic vulnerability. In order to understand if seismic sources properties could have significantly affected the damage pattern, several seismological aspects were deepened. Indeed, the analysis of broad-band recordings of the mainshock revealed that this earthquake was characterized by a strike slip mechanism and suggested that the rupture scenario was unilateral toward North-West. To quantify source duration and directivity effects, the velocity pulse duration was examined and the empirical Green's function (EGF) scheme was applied to isolate and explore the mainshock rupture kinematics. As a seismological result, directivity effects could be observed for this moderate size earthquake at distance of about 40 km. These seismological evidences seem to be in accordance with the damage scenario, even if this correlation has to be confirmed by means of deepened studies, based on wider and complete data set.

### AN EVALUATION OF STRONG GROUND MOTIONS AND FAILURES OF NATURAL AND CUT SLOPES INDUCED BY KASHMIR EARTHQUAKE OF OCTOBER 8, 2005 – ID 1352

*O. Aydan, Tokai University, Japan*
*M. Hamada, Waseda University, Japan*
*K. Konagai, University of Tokyo, Japan*

A large devastating earthquake occurred in Kashmir on Oct. 8, 2005 at 8:50 (3:50UTC) local time of Pakistan. The depth of the earthquake was estimated to be about 10km and it had the magnitude of 7.6. The earthquake killed more than 75000 people, most of which was on Pakistani side of Kashmir. About 2000 people were killed in Indian side of Kashmir. The earthquake resulted from the subduction of Indian plate beneath Eurasian plate, and the faulting mechanism solutions indicated that the earthquake was due to thrust faulting. Although there was no surface fracture as a result of the faulting, the valley between Garhi to Balakot through Muzaffarabad may be the location where the fault should have appeared. The largest city influenced by the earthquake was Muzaffarabad, which is the capital of Pakistani Kashmir region. Balakot town was the nearest settlement to the epicenter and it was the most heavily damaged. Because of loose deposits resulting from steep slope degradation and slope failures, it would have been extremely difficult to differentiate the effect of surface effects of the faulting. The earthquake caused extensive damage to housing and structures founded on these loose deposits. Furthermore, extensive

slope failures occurred along Neelum valley, which obstructed both river flow and roadways. The authors were the members of the joint team of JSCE and AIJ. In the first part of this article, strong ground motions of instrumented areas and non-instrumented area are evaluated through different direct measurements and indirect techniques utilizing the objects, which was slid and/or toppled and they are compared with each other. Then a geotechnical evaluation of the failure of natural and cut slopes induced by the earthquake is presented and their implications on civil infra structures and site selection for reconstruction and rehabilitation are discussed.

### THE PARAMETERS AND BACKGROUND OF SEISMOTECTONIC CONDITIONS OF TBILISI EARTHQUAKE ON APRIL 25, 2002 – ID 1495

*N. Tsereteli, Institute of Geophysics, Georgian Academy of Scien, Georgia*
*O. Varazanashvili, Institute of Geophysics, Georgian Academy of Scien, Georgia*
*T. Mukhadze, Inst of Struct. and Earthquake Engineering, Georgia*

On April 25, 2002 at 22:41 local time, a moderate earthquake Ms = 4.6 occurred in Tbilisi region, Georgia. The main kinematic and dynamic parameters of earthquake and the geometric size of the source are determined. The isoseismal map has been constructed. Quite good agreements are observed between macroseismic and instrumental epicenter as appropriate to weak and moderate earthquakes. The central part of Tbilisi urban area was evaluated as I0 = VII macroseismic intensity. Here is observed the local zone with maximum intensity VII – VIII, separation of witch was based upon on the special macroseismic investigation. The main shock was preceded by five foreshocks. Among of them only two events (11 04 2002, Ms = 3.7 and 21 04 2002, Ms = 2.0) were felt by much of capital's population. According to the macroseismic data, seismic intensity of these events was estimated as V and IV in MSK scale correspondingly. Only in the first week more than 350 events with magnitude range MS = 0¸3 were fixed and these process continued to the end of the year with decreasing activity. The focal mechanism solution was constructed, using P wave polarity data. This solution has a mechanism involving right lateral strike slip motion trending NW – SE. The Mean orientation of T and P exes for this event was NW-SE and NE-SW respectively. Geological interpretation of the earthquake occurrence has been carried out in the west end of Achara-Trialeti tectonic zone's active faults system. The important seismotectonic results have been taken on the bases of instrumental and macroseismic investigation. Tbilisi earthquake on April 25, 2002, has revealed the seismogenesis regularity of this region. It was shown the existence of active diagonal Tbilisi-Mtkvari fault zone at the end of Achara-Trialeti tectonic zone, witch is essential for a capital hazard assessment.

### FINAL RESULTS ON MACROSEISMIC INTENSITIES FOR OCTOBER 27, 2004 EARTHQUAKE (M=6) FROM VRANCEA SEISMOGENIC ZONE (ROMANIA). – ID 1854

*A. Pantea, National Institute for Earth Physics, Romania*
*A. Constantin, National Institute for Earth Physics, Romania*

Vrancea seismogenic zone (VSZ) is situated on Romanian territory, in the region of the bow of Oriental Carpathians or more precise where the Carpathian arc bends, in a well-confined focal volume. The Vrancea seismogenic zone (VSZ) is one of the most conspicuous earthquake-prone zones and extremely peculiar seismic source world-wide, as well as the Romania's main seismic hazard source and consequently focused the attention of numerous seismologists (Marza et al., 2002). The Vrancea seismogenic zone (VSZ) is centred upon the triple junction of three tectonic units: the East – European plate, the Inter-Alpine subplate and the Meson subplate. This situation, is interesting as a particular seismotectonic process in itself and leads to the generation of crustal and subcrustal or intermediate depth (the 60 to 200 km. deep) earthquakes. During the last sixty years, Romania was struck by two destructive intermediate earthquakes occurred in the Vrancea region on November 10, 1940 (MGR=7.4) and on March 4, 1977 (MGR=7.2). These was among the most damaging earthquakes in Romania originated in the Vrancea region. On October 27, 2004, a moderate size earthquake of magnitude Mw= 6.0, occurred in the north-eastern part of the Vrancea seismogenic zone, at 100 km depth. The intensity in epicenter area was VII. The quake was felt in several cities located NE and S from epicenter (Iasi, Bacau, Focsani, Bucharest) and also felt in the Republic of Moldova, Ukraine, Bulgaria and Turkey.

## SS 1: Tsunamis in the European Mediterranean Region and the Sumatra Earthquake and Tsunami in the Indian Ocean

Wednesday 10:45 - 12:15 – Room 7+8

### TO THE PROBLEM OF GENERATION OF STRONG TSUNAMIS IN INDIAN OCEAN AND MEDITERRANEAN SEA – ID 461

*R. Mazova, Nizhny Novgorod State Technical University, Russian Federation*

In this contribution, there are presented the results of numerical simulation of surface water wave (on the basis of shallow water equations) generated by both tsunamigenic earthquakes and underwater landslides. In first case, the subduction keyboard model of tsunamigenic earthquakes [1] is used for numerical simulation of features of the near-Sumatra source of Indian Ocean tsunami 26 December 2004 caused by oblique subduction. This a model treates the anomalously long source of this tsunami as due to multiblock piston mechanism with non-simultaneous realization of each keyboard block which 'chord' have led to giant tsunami. Analysis of dynamical process of formation of seafloor displacements demonstrates that character of this process essentially determines the tsunami wave height distribution at the coast. It is especially important for the local tsunami. It is obviously than knowledge of seafloor displacements and velocities during earthquake entirely provides solution of the problem of tsunami wave formation. In second case, the novel elastoplastic model of landslide body is used for numerical simulation of features of landslide in the Corinth Bay where 17 February 1963 the damaging tsunami due to the landslide was formed. Such landslides as known are characteristic for the Mediterranean Sea region. Under calculations there were taken layer density, shear modulus, bulk modulus, cohesion, maximal friction angle, and tensile strength. The simulation of initial, preliminary stressed state of slope with sediments formed under action of its own weight and saturation with the water under sea pressure was performed. The rheological effect of decrease sediment mass and possibility of landslide-mass liquefaction under conditions of seismic or any external action was also taken into account.

[1] L.I.Lobkovsky, R.Kh.Mazova, I.A.Garagash, L.Yu.Kataeva, N.S.Petrukhin, Geophys.Res.Abstr.of EGU General Assembly, Vienna, Austria, 24-30 April 2005, 7, 00949

### SOURCES OF STRONG TSUNAMIS IN THE EURO-MEDITERRANEAN REGION – ID 1997

*G. Papadopoulos, Institute of Geodynamics, National Observatory, Greece*
*E. Daskalaki, Institute of Geodynamics, National Observatory*
*G. Diakogianni, Institute of Geodynamics, National Observatory, Greece*
*A. Fokaefs, Institute of Geodynamics, National Observatory, Greece*

Tsunami waves in the Euro-Mediterranean region are associated mainly with the occurrence of strong earthquakes but also with volcanic eruptions and earth slumps. A catalogue of tsunamis generated from the antiquity up to the present time is compiled. The size of each tsunami event has been reassessed on the basis of the new 12-point tsunami intensity scale. The rupture zones of the strong tsunamigenic earthquakes are determined from

empirical relations between the dimensions and orientation of rupture zones, focal parameters (e.g. magnitude, focal mechanism) and macroseismic parameters (e.g. maximum intensity, high intensity isoseismals) of the earthquakes. A map is presented for the first time of the seismic and non-seismic sources of tsunamis in the Euro-Mediterranean region. Implications for the assessment of tsunami hazard as well as for the support of tsunami warning systems in the Euro-Mediterranean region are discussed.

### 26TH DECEMBER 2006 INDIAN OCEAN TSUNAMI: THE INTENSITY FIELD – ID 326

*E. Daskalaki, National Observatory,Institute of Geodynamics, Greece*
*A. Fokaefs, National Observatory,Institute of Geodynamics, Greece*
*K. Orfanogiannaki, National Observatory,Institute of Geodynamics, Greece*
*G. Papadopoulos, National Observatory,Institute of Geodynamics, Greece*

The Mw=9.1 Sumatra earthquake of 26 December 2004 triggered one of the most devastating tsunamis. As a result, a great number of coastal sites around Indian Ocean from near-field up to distances of more than 6000 km, corresponding wave travel time was up to 8 hrs, have been affected. Many research groups, including the present one, made valuable observations during several post-tsunami field surveys. All the collected data have been compiled and classified according to their geographical distribution. In every observation point, the various effects of the tsunami, such as the degree of destruction or damage, have been transformed to tsunami intensities. Both the classic 6-point and new 12-point intensity scales were used. Comparison between the tsunami intensity and the tsunami wave run-up was made and the relations between them are investigated. Intensity attenuation laws are also investigated. The pattern of tsunami intensity field obtained is compared with the pattern of the earthquake intensity field.

### DECEMBER 26, 2004 GREAT SUMATRA EARTHQUAKE: A POST- TSUNAMI AND EARTHQUAKE SURVEY IN AND AROUND ANDAMAN ISLANDS – ID 23

*D. Shanker, Indian Institute of Technology Roorkee, India*

Massive earthquake of 9.0 magnitude that occurred at 07.58 local time on 26th December 2004 at the interface between the India and Burma plates off the west coast of Northern Sumatra, Indonesia caused tsunami disaster to several countries in the Indian Ocean. The quake was followed by a few tremors subsequently also. The hardest hit were the countries of Indonesia, Srilanka, India and Thiland. The death toll exceeds 300,000 people and is a major disaster for the 40 years. This paper presents a reconnaissance report of study of damage due to tsunamigenic megathrust Sumatra earthquake and tsunami, in and around Andaman and Nicobar Island. This area was experienced largest shaking and hardest hit by tsunami. Although, earthquake induced damages (ground deformations and cracks-geotechnical aspects of damages, damages to structures) are different in nature compared to those caused by Tsunami waves damages (geotechnical aspects of damages, damages to marine structures). The earthquake has produced intense subsidence and upliftment at the ocean bottom at different places as seen from the field evidence. At several places lateral spreading, ground uplifts (about a meter), grounding slumping and deep cracks have been observed. At Port Blair, the sea water level has risen permanently by about 1 meter, suggesting a subsidence of the landmass, whereas in Middle Andaman Islands emergence of new shallow coral beaches suggests uplift. Liquefaction with ejection of sand and copious water and also decrease of water level in several wells were observed in the part of the Diglipur area. At Baratang an older mud volcano became active again after the earthquake and also several new small mud volcanos erupted along with large ground deformation. Effect of tsunamis were dominant in all coastal regions of island in South Andaman and this kept on increasing southwards (Little Andaman, Car Nicobar and Great Nicobar).

### MODELLING THE NEXT LIKELY TSUNAMI IN SUMATRA – ID 1943

*J. McCloskey, University of Ulster, Ireland*
*A. Antonioli, University of Ulster, Ireland*
*A. Piatanesi, INGV, Italy*
*S. Steacy, University of Ulster, Ireland*
*K. Sieh, California Institute of Technology, United States*
*S. Cianetti, INGV, Italy*
*S. Nalbant, University of Ulster, Ireland*
*C. Giunchi, INGV, Italy*
*M. Cocco, INGV, Italy*

Following the recent earthquakes in the Sumatra region, there is a significantly increased risk of a large (M>8) earthquake to the west of Sumatra. The coseismic Coulomb stress increase due to the combination of the December 2004 and the March 2005 events is high under the island of Siberut and it has also been shown that the Sunda trench megathrust has been locked in this area since 1797 and has thus accumulated over 10m of strain. The megathrust under the Mentawai Islands south of Siberut has probably not slipped since 1833 which again suggests the possibility of on the order of 10m of slip. An event rupturing the megathrust beneath Siberut might be expected to propagate southward into this area resulting in a great earthquake of magnitude M 8-9. Here we show results for a range of possible tsunamis that might be produced by such an event. The tsunamis are simulated by: 1) Generating a suite of fractal slip distributions for 4 possible lengths - 210, 330, 630, and 840 km. 2) Filtering these distributions them based on geologic knowledge of past ruptures. 3) Using a 3D finite element model to compute the seafloor displacements for each simulated event. 4) Solving the hydrodynamic equations using a finite difference method to compute tsunami wave heights and wave energies along the coast of Sumatra and in the Indian Ocean. We have digitized the bathymetry just offshore Sumatra as well as its coastline in order to improve the resolution in this vitally important area.

### DEVELOPMENT OF PLANNING AND ZONING CRITERIA FOR THE TSUNAMI THREATENED COASTLINE OF SRI LANKA – ID 1224

*J. J. Wijetunge, University of Peradeniya, Sri Lanka*

The Sumatra tsunami on the 26th of December 2004 clearly indicated that the risk of tsunami inundation and damage is not evenly distributed along the coastline of Sri Lanka. In general, such non-uniform tsunami height and inundation could be attributed to many factors including the travel path of the tsunami waves, the energy focusing effects, the shape of the coastline, the nearshore bathymetry, the land topography and the surface roughness. However, as further detailed studies are necessary for us to understand and determine which of the above factors have primarily influenced the inundation distance and the consequent damage at a given location, the author carried out a detailed field survey of the tsunami heights, the extent of inundation as well as the degree of damage along the affected coastline of Sri Lanka.

The data gathered from the field survey together with available bathymetry and topography maps have been employed to understand and interpret the spatial distribution of the inundation due to the recent Sumatra Tsunami. Such information is vital to identify high-hazard and low-hazard site areas in formulating pot-tsunami coastal land use plans as well as for evacuation of people during tsunami warnings.

Accordingly, the findings of the study have been used to carry out a vulnerability assessment for potential tsunami (as well as storm surge) damage and to draft preliminary guidelines for planning and zoning criteria, for the coastline of Sri Lanka.

This investigation received financial support from NSF Grant No. RG/2005/DMM/02.

## SS 2-I: Earthquake Loss Modelling : From Earth Sciences to Insurance Applications

Tuesday 10:45 - 12:15 – Room 3

### ARE SURPRISINGLY HIGH LOSS LEVELS INEVITABLE – ID 350

*A. Allmann, Munich Reinsurance Company, Germany*

In view of strongly increasing loss potentials due to natural catastrophes, complex probabilistic risk models have become a major component of pricing and risk control in the insurance sector. Although the losses from the 1994 Northridge earthquake were greatly underestimated, confidence in these models has continued to rise. Results are often used unchallenged, and people tend to forget that the outcome from a model is not the absolute truth. The 2004 and 2005 hurricane seasons and especially the losses due to hurricane Katrina clearly illustrated the uncertainties inherent in all models and called into question the reliability of cat models in general. Loss ratios, a key component of all models, are based on sparse empirical data or on engineering theory. In earthquake modelling, powerful computers allow a degree of complexity and level of detail without sufficient empirical data to support it. Therefore, engineering theory has gained widely in importance. Unfortunately, losses paid by the insurance industry show that issues such as clients' expectations, claims handling, fraud, the actual extent of coverage, political pressure, demand surge and complex business dependencies all play a large role in determining the final losses. In addition, the quality of the underlying exposure data does not match the complexity of the model, thus creating scope for huge handling errors. Modelling remains the most effective measure to quantify risk and should be the basis for all risk management; however, it has to be taken into account when utilizing the results that these are far from perfect. Otherwise it seems inevitable that there will other unpleasant surprises down the line. Europe, characterized by high value concentrations, a moderate but uncertain hazard estimate, and poor exposure data would be a prime candidate.

### EARTHQUAKE TOKYO: HOW RESULTS FROM A PUBLIC-PRIVATE RESEARCH PROJECT AFFECT AN INSURANCE RISK MODEL – ID 1673

*M. Bertogg, Swiss Reinsurance Company, Switzerland*
*A. Dodo, Swiss Reinsurance Company, Japan*
*B. Grollimund, Swiss Reinsurance Company, Switzerland*
*G. Kerland, Swiss Reinsurance Company, Switzerland*

Japan has experienced in its history a long series of strong and devastating earthquakes, resulting in countless casualties. In particular in the Greater Tokyo area an exceptionally high population and value concentration coincides with very high seismic hazard and makes Tokyo to a focal spot of interest for emergency planners as well as insurance companies. The earthquake history of Greater Tokyo is marked by the devastating 1923 Kanto event, preceded by the documented 1703 event of similar size, as well as a set of numerous previous events, of which we only have paleoseismic evidence. What is the recurrence probability for such a devastating earthquake taking the obvious cyclicality into account?

This question has been addressed by a Japanese/US research team in a public/private partnership with a reinsurance company. The team found that the probability for a Kanto-type earthquake affecting Tokyo in the next few decades is now considerably lower than previously assumed. However, in turn the probability for other, more local sources affecting Tokyo has been strongly increased. The focus of highest seismic hazard has shifted to the Tokai area southwest of Tokyo.

The current risk management process for an insurance company underwriting earthquake risk in Japan has historically been focused on Greater Tokyo. How has it been affected by these changes? A state-of-the-art insurance risk model framework has been used to implement the detailed scientific findings. Through the co-operation with the researcher's team, we have been able to bridge state-of-the-art seismic hazard assessment with an insurance risk model. Applying this model to a typical building stock in Japan we derived damage-exceedance-probability curves. On a local scale, the risk landscape changed considerably, while on a Japan-wide scale the changes are surprisingly small.

### EARTHQUAKE LOSS ESTIMATION MODELS: TIME TO OPEN THE BLACK BOXES? – ID 834

*J. Bommer, Imperial College London, UK*
*R. Pinho, ROSE School, Italy*
*R. Spence, Cambridge University, UK*

During recent years the field of earthquake loss modelling has developed rapidly, driven by the needs of both governments and the reinsurance industry to be able to estimate likely losses from future seismic events. Particular impetus for this process was provided by the 1994 Northridge and 1995 Kobe earthquakes, both of which caused unprecedented economic losses, the former particularly affecting the insurance industry, and the 1999 Kocaeli and Duzce earthquakes which placed an enormous financial burden on the Turkish government.

The mostly widely used models are those developed as proprietary software packages by commercial catastrophe modelling firms. A common characteristic amongst the majority of commercial loss models is that the details of their inner workings are not revealed to the user, who often will not know even which methodological approach is being used to calculate the losses, much less how earthquake scenarios are being modelled, which ground-motion parameters are being predicted, and how the vulnerability of the exposed building stock is being defined. Moreover, the user is not informed of the underlying assumptions in the model and how uncertainties in each of the input parameters is represented in the calculations and hence in the output. The use of such 'black boxes' thus requires blind acceptance of the output and this does not allow informed decision making.

The publication of transparent approaches to loss modelling such as HAZUS and the growth of openly published academic research in the field of earthquake loss estimation, which includes studies demonstrating the sensitivity of the results to the adopted method and the uncertainties associated with the input parameters, make it increasingly anachronistic to continue the practice of distributing 'black box' models. In this paper the case is presented for transparency and for the introduction of bench-marking procedures to calibrate all models to industry standards.

### EARTHQUAKE LOSS ESTIMATION MODEL FOR THE RE-INSURANCE INDUSTRY IN INDIA – ID 1168

*S. Francis, RMSI PVT. LTD., India*
*R. Mohindra, RMSI PVT. LTD., India*
*K. Jaiswal, RMSI PVT. LTD., India*

Nearly two-thirds of the Indian sub-continent is prone to earthquakes. Highly seismic regions, such as the north and north-eastern segments of the Himalayas, Rann of Kutch and Andaman & Nicobar Islands, in the sub-continent have generated some of the most intense earthquakes of the world. As revealed by some of the recent events, the potential social and economic consequences associated with earthquakes occurring in these regions can be very severe, due to their proximity to large urban agglomerations such as Delhi, Mumbai, Ahmadabad, etc. Despite a low overall insurance penetration in India, earthquake related risk to insured assets is perceived to be high owing to high insurance losses in the recent Gujarat (2001) earthquake and due to the fact that more than 80% of the insured assets consisting mostly of commercial and industrial property is concentrated in and around seismically active regions. RMSI recently developed a probabilistic earthquake loss model capable of estimating average annual and return period losses to insurance portfolios at CRESTA, state and district levels. First of its kind in the Indian re-insurance industry, the probabilistic model incorporates state-of-the-art modeling methods and the latest region specific research on earthquake hazard and building vulnerability. The basic framework of the model consists of Hazard, Vulnerability & Financial modules. The Hazard module

comprises 42,000 stochastic events generated from 93 source zones delineated based on a comprehensive earthquake event catalog spanning more than 400 years combined with scientific research on seismotectonics and geology. The Vulnerability module comprises vulnerability functions that correlate hazard intensities with level of damage for residential, commercial and industrial buildings. The financial module outputs loss estimates for insurance exposures based on pre-defined insurance structures. The model is calibrated and validated against historical event losses and will be used by insurance and re-insurance companies for upcoming renewals this year.

### USE OF PROBABILISTIC EARTHQUAKE LOSS ESTIMATION MODELS FOR INSURANCE RATING. CASE STUDIES. – ID 653

*L. Chiroiu, Benfield, UK*
*M. Simic, Benfield, UK*
*C. Dyer, Benfield, UK*

Fully probabilistic loss estimations models are usually required for reinsurance purposes, for estimating PMLs and generating the loss exceedance probability curves. An alternative output of such models is the annual average loss (AAL), which calculate the annual premium due to earthquake peril. By varying and combining different parameters such as building types and condition, occupancies, coverages and locations, an insurance rating tool could be derived from a normal loss estimation model. In this paper we present the application of Benfield GAP Quake models for deriving an earthquake rating tool for Romania and Germany. Based on a fully probabilistic hazard model which generates synthetic events over 50,000 years, on EMS-98 scale and on reconstruction cost ratios, the AAL is obtained for different locations and representative structure types. For instance, a building type C after EMS-98, located in Buzau county, Romania, neighbouring high hazard Vrancea zone, would have a yearly earthquake insurance tariff of 2.06 ‰. Such an application could represent a very interesting tool for pricing the yearly cost of earthquakes, for insurance industry and also for the governmental natural hazard mitigation schemes.

### ASSESSMENT OF EARTHQUAKE INSURANCE PREMIUM RATES FOR THE TURKISH CATASTROPHIC INSURANCE POOL – ID 1325

*M. S. Yucemen, Middle East Technical University, Turkey*

After the two major earthquakes in 1999, the Government of Turkey has decided to enforce the earthquake insurance on the nationwide basis with the sole purpose of privatizing the potential risk by offering insurance via the Turkish Catastrophic Insurance Pool (TCIP) and then exporting the major part of this risk to the international reinsurance and capital markets. All registered residential dwellings are required to be in the compulsory earthquake insurance coverage.

In the implementation of the obligatory insurance program, the earthquake insurance premium rates were set by the Prime Ministry of the Turkish Republic, the Under-secretariat of Treasury and charged by the insurance companies under the control and coordination of TCIP. Thus, this study aims at presenting a simple model for the assessment of earthquake insurance premium rates by considering the damage statistics and the potential seismic hazard. The model integrates the information on seismic hazard and the information on expected earthquake damage on engineering facilities in a systematic way, yielding to estimates of earthquake insurance premium rates.

The quantification of the future earthquake threat is achieved by making use of the probabilistic seismic hazard analysis (SHA) techniques. Through the probabilistic approach, improved data processing methods are utilized along with a comprehensive seismic data base corrected with respect to incompleteness, dependence and differences in the magnitude scales. Moreover, up-to-date information is employed in the delineation of seismic sources and in the use of ground motion prediction equation.

For the estimation of damage that may occur during future earthquakes, damage probability matrices (DPM) are constructed from observational and estimated data. Damage statistics of approximately 120,000 buildings are compiled and processed.

The proposed model is used for the assessment of the earthquake insurance premium rates for reinforced concrete and masonry buildings constructed in different seismic zones of Turkey.

## SS 2-II: Earthquake Loss Modelling : From Earth Sciences to Insurance Applications

Tuesday 13:30 - 15:00 – Room 3

### EUROPEAN SEISMIC RISK MODEL COVERING ITALY, SWITZERLAND, AUSTRIA, GERMANY AND BELGIUM – ID 2024

*C. Williams, Risk Management Solutions, United States*
*M. Nyst, Risk Management Solutions, United States*
*T. Onur, Risk Management Solutions, United States*
*P. Seneviratna, Risk Management Solutions, United States*
*A. Baca, Risk Management Solutions, United States*
*A. Sorby, Risk Management Solutions, UK*

A seismic risk model for Europe has been developed to assisted insurers and reinsurers in assessing their financial risk posed by earthquakes. This model was covers Italy and several countries in central Europe including Switzerland, Austria, Germany and Belgium. This presentation summarizes the methodology and data within the model and includes a discussion of the key results from the hazard and risk perspectives.

The earthquake, risk-model framework has four components. First, the stochastic event set is determined, as well as its associated event probabilities (Nyst et al., 2006, 1st ECEES). A ground-motion model including geotechnical data is added to complete the seismic hazard model (Onur et al., 2006, 1st ECEES). To determine risk, regional building vulnerability curves (Baca et al., 2006, 1st ECEES) and a financial model are incorporated. An insurer property exposure database was developed to determine the insured seismic risk in these countries.

Using this model, examination of resulting hazard maps (250, 500 and 1000 years) and of city-level, hazard-curves gives insight to the key drivers of risk across the region. Hazard de-aggregation allow for examination of key drivers of risk in terms of seismic sources and events types. Examination of loss costs for residential and commercial (short and mid-rise) structures gives insight into the risk perspective for these various lines of business. Finally, incorporation of the insurer property exposure allows for an examination of the insured risk across the region and between exposure concentrations including Rome, Zurich, Berlin, Vienna and Antwerp.

### CURRENT AND EMERGING INSURANCE MARKETS - EARTHQUAKE MODELS AND RISK TRANSFER TECHNOLOGY – ID 1287

*S. Tabuchi, Willis Limited, UK*
*R. Sanders, Willis Limited, UK*
*J. England, Willis Limited, UK*

In 2000, the Turkish national insurance pool was launched in order to facilitate the provision of earthquake insurance following the 1999 Kocaeli event. This pool development provided a key step forward in the development of national earthquake insurance pools. Following its successful and innovative launch many national and local governments and insurance authorities showed an interest in setting up their own earthquake pools. These authorities have identified a requirement to quantify potential human and economic losses from damaging earthquakes in order to design and develop a methodology for dealing with such an event and to take forward the implementation of a pool.

The standard methodology for identifying potential losses involves building hypothetical historic, or fully probabilistic earth-

quake hazard models at a national or regional level. These physical hazard models are integrated with economic modules which express the output as a financial amount.

The wider catastrophe modelling community has defined the fundamental building blocks for earthquake modelling, and individual regions requirements for complexity and completeness are defined and constrained by data availability and user needs. The components of the catastrophe model are frequently reliant on recent or new scientific and engineering research provided by the academic community and the need to invest in and encourage data improvement and research advancement is stressed.

In this paper, examples of pools and models from Turkey, Algeria and Switzerland are used to illustrate three very different situations faced by developers, in terms of; seismicity, data availability and physical accessibility. The differences in approach taken by the commercial, intermediary and academic communities are discussed and a list of ideal data and research requirements is presented. The technical development of earthquake insurance pools and likely regions for new pools are also touched upon.

### EARTHQUAKE LOSS MODELLING FOR LOW SEISMIC REGION OF EASTERN AND NORTHERN EUROPE – ID 2014

*M. R. Zolfaghari, EQECAT, UK*
*K. Campbell, EQECAT, United States*
*N. Shome, EQECAT, United States*

Catastrophe loss modelling has been under rapid development in the recent years. This is mainly due to significant demands for natural catastrophe models and their applications in the financial and insurance industry. Due to the high severity and low frequency of natural catastrophe such as earthquakes, the use of traditional actuarial methods based on historical loss records is inadequate and incomplete. Computer risk models today are used to evaluate potential losses from future events and provide facilities for better controlling exposure to potential losses. These computer models provide sound basis for risk pricing for insurance and reinsurance portfolio management. Information obtained from this type of modelling is ideally suited to the regional risk consideration of traditional financial entities as well as to the growing insurance catastrophic market in the region. The first generation of the earthquake loss model for European region was developed in the late 1990's and has been used by many insurance and reinsurance companies for various insurance portfolio analyses. In this paper the methodology and preliminary results for a new earthquake model for the European region is presented. The seismic hazard, the built environment inventory and the building vulnerabilities are probabilistically convoluted to estimate probabilistic losses. Such results once implemented in user friendly financial software, are used by insurance and reinsurance companies to estimate their potential exposure to seismic hazards. The main advantages of this model are its high resolution stochastic event set, detailed seismic model, and a range of vulnerability functions describing various building types and contents. The new model uses the latest information on regional seismotectonic to develop a new regional seismic hazard model for continental Europe. This model benefits a high geographical resolution for the underlying administrative units to capture detailed variation of seismic hazard and to enhance the modelling of soil effect

### INFLUENCE OF GROUND MOTION MODELLING ON LOSS EXCEEDANCE CURVES FOR PORTFOLIOS OF BUILDINGS – ID 621

*H. Crowley, ROSE School, Italy*
*J. Bommer, Imperial College, UK*

This paper focuses on a detailed study of the description of the seismic hazard in an earthquake loss model and the sensitivity of the loss results to changes in the ground motion model. A case study loss model is set up for the Marmara Region in Turkey through the collection of databases on the building inventory for a selection of sites, the structural characteristics of the buildings, the earthquake activity of the region, and the tectonic environment. Once the seismicity model is created, two options for modelling the seismic hazard (in terms of the annual frequency of exceedance of given levels of ground motion) are studied: the first considers the use of probabilistic seismic hazard curves and the second the use of stochastically generated earthquake catalogues and ground motions. The two methods are then used in the calculation of curves of direct loss versus annual frequency of exceedance using a displacement-based earthquake loss assessment methodology. The theoretical superiority of the stochastically-generated ground motions due to the possibility to model a correlated ground motion field with separate components of inter- and intra-event variability is discussed. Subsequently, the following alterations to the stochastic ground-motion model are carried out to test their relative influence on the loss results: use of a time-dependent (Renewal) earthquake occurrence model; variation of the proportions of inter- and intra-event variability; consideration of distance-dependence on the spectral damping reduction factor; and inclusion of magnitude-dependence on the corner period of the displacement response spectrum. The use of a Renewal model as opposed to the Poisson model is seen to cause the largest impact on the loss exceedance curves for this particular loss model, though the influence on the average annual loss is found to be relatively insignificant.

### SPATIAL CORRELATION - A KEY FACTOR IN LOSS ESTIMATION FOR INSURANCE – ID 1301

*W. Dong, RMS, United States*

Most engineering hazard analysis has been focused on single locality, say a nuclear power plant. The analysis is deep, considering a great deal of uncertainties; however it is only concentrated on single location. Spatial correlation was not an issue. At the other end, insurance application requires to estimate loss for spatially distributed portfolio. In that case, spatial correlation of losses plays significant role in loss allocation among all stakeholds, particularly for reinsurers. An example will be given to demonstrate why the spatial correlation is so important to the loss estimation for insurance portfolio.

There are many sources which contribute to spatial correlation and will be discussed from engineering perspective. However, this paper will focus on how to use the observed loss (claim) data to quantify the spatial correlation. Two approaches (simulation approach and mutating approach) will be explored and the results will be presented. The result shows clearly that correlation is depended on the distance between locations and correlation is decayed with distance increase.

Accurate way to calculate pair wise correlation in a large portfolio is a formidable (combinatory explosion) task. For practical purpose, a macro correlation weight method is presented and recommended for implementation. Further research for earthquake engineering to improve quantification of spatial correlation will be discussed in the concluding remark.

### SYNTHETIC EARTHQUAKE CATALOGUES FOR A PROBABILISTIC EARTHQUAKE HAZARD MODELLING: CASE STUDY CHINA – ID 1672

*P. Tscherrig, Swiss Reinsurance Company, Switzerland*
*M. Bertogg, Swiss Reinsurance Company, Switzerland*
*M. Guatteri, Swiss Reinsurance Company, United States*
*P. M. Mai, Swiss Seismological Service, Switzerland*
*B. Grollimund, Swiss Reinsurance Company, Switzerland*
*G. Kerland, Swiss Reinsurance Company, Switzerland*

For insurance earthquake risk modelling purposes, we developed a novel methodology to create synthetic earthquake catalogues. The method is based on a sampling-with-replacement technique from a given earthquake catalogue and creates synthetic earthquake catalogues that might be representative for the earthquake occurrence in the forthcoming millenniums.

As a case study, we present the seismic hazard and risk assessment results based on this method for the mainland China. The output of the method, a synthetic earthquake catalogue, has been used to create seismic hazard maps. The resulting hazard maps are

on a regional scale very comparable to maps generated with considerably more detailed methods. The model development based on our new method has been found to be very resource efficient. We also apply the model to a typical Chinese residential building stock – as a case study in an insurance model framework. The method can also be modified in order to create a probabilistic representation of earthquake scenarios for emergency planning purposes or to conduct detailed hazard de-aggregation studies.

Compared to traditional PSHA-analyses, the proposed method allows with a comparatively minor effort to generate a comprehensive set of earthquake hazard information. It either allows a pragmatic representation of the seismic hazard as well as the incorporation of detailed seismological models, depending on the required precision.

A nontrivial advantage is also that the method is conceptually very demonstrative and it is therefore easy to communicate its output to all parties involved in a risk assessment process. Hence we recommend to work with this method also outside of the boundaries of traditional insurance risk modelling.

## SS 2-III: Earthquake Loss Modelling : From Earth Sciences to Insurance Applications

Tuesday 15:30 - 17:00 – Room 3

### THE USE OF RISK IN DESIGN: THE ATC 58 PERFORMANCE ASSESSMENT PROCEDURE – ID 647

*C. Comartin, CDComartin, Inc., United States*
*R. Hamburger, SGH, United States*
*A. Whittaker, SUNY-Buffalo, United States*
*R. Bachman, Consultant, United States*

The US Federal Emergency Management Agency (FEMA) is supporting the Applied Technology Council (ATC) to develop a next generation of performance-based seismic design guidelines for buildings. The project, ATC-58 will result in the capability to base design decisions explicitly on the expected performance of the building in future earthquake events. Performance is measured as the risk of experiencing three types of losses: • Deaths and serious injuries. • Direct capital losses attributable to damage contents. • Indirect losses attributable to the loss of use for repair or reconstruction. This characterization of performance provides a common framework for design decisions that can be readily adapted to the perspectives of all stakeholders (e.g. owner, architect, engineer, contractor, regulator, lender, insurer). It also facilitates efficient planning and design decisions through comparison of costs and benefits of various alternatives. This paper describes a procedure to assess risk and potential losses for individual buildings. Shaking hazard is defined to specify how intense shaking might be and how often it is likely to occur. Corresponding ground motions are applied to a nonlinear model of the building to calculate the demands (forces and distortions) on structural and nonstructural components and systems produced by each ground motion. Up to this point the procedures are somewhat similar to those that have been used by engineers for design purposes. The next steps depart from traditional design procedures. The demand is used to generate an estimate of damage to the building including damage to the structure, to nonstructural components and systems, and to contents. Finally, the projected losses are determined based on the total damage and consequence functions that translate the damage into human losses, capital losses, and downtime. A practical example is included to illustrate application of the procedure.

### DETAILED EARTHQUAKE LOSS ESTIMATION MODEL FOR COMPREHENSIVE RISK MANAGEMENT – ID 724

*O. D. Cardona, Evaluación de Riesgos Naturales, ERN Colombia, Colombia*
*L. E. Yamín, Evaluación de Riesgos Naturales, ERN Colombia, Colombia*
*S. Arámbula, Evaluación de Riesgos Naturales, ERN Colombia, Colombia*
*M. G. Ordaz, Evaluación de Riesgos Naturales, ERN Consultores, Mexico*
*O. Mahul, World Bank, United States*
*F. Ghesquiere, World Bank, United States*

Understanding probable losses and reconstruction costs due to earthquakes creates powerful incentives for countries to develop planning options and tools to cope with risk, including allocating the sustained budgetary resources necessary to reduce those potential damages and safeguard development. In the framework of the Vulnerability Reduction Program in Colombia supported by the World Bank and the Inter-American Development Bank Action Plan for Improving Disaster Risk Management, a specific catastrophic risk model has been developed to evaluate, building by building, the probabilistic losses of different portfolios and pure premiums, taking into account the seismic microzonation of the cities. This model has been used to evaluate the fiscal contingency liabilities of the government and to build an optimal structure for risk transfer and retention, considering contingency credits, reserve funds, insurance/reinsurance, and cat bonds. In addition, an innovative insurance tool has been implemented with the property tax to cover the private buildings, including all low-income owners using cross subsidies. Lastly, the model allows the evaluation of an exceedance probability curve of benefit-cost ratio, providing a ground-breaking tool for decision-makers to analyze the net benefits of the risk mitigation measures, such as the earthquake retrofitting and the seismic code enforcement. This paper describes the model and the derived abovementioned tools using the results of loss scenarios and the strategies implemented in cities as Bogota and Manizales in Colombia.

### TURKISH CATASTROPHY INSURANCE POOL – ID 1785

*F. Özay, Turkey*

The paper describes the brief history and then the functioning of the Turkish Catastrophy Insurance Pool which is a mandatory insurance scheme effective in Turkey as from year 2000. It provides cover against earthquake risk for the structural part of residential buildings. The functioning of the scheme will be detailed in relation to the scope of coverage, statistical characteristics of risks consisting of building type, number of stories, age, base area and the relation between the earthquake accumulation figures and the PML levels acceptable and used in common practice.

The idea of the pool is to generate adequate funds in years to reduce the need for reinsurance protection of the covered risks but until this happens substantial amount of cover is essential for the security and future of the system. There, the effect of PML (probable maximum loss) becomes very important as it leads to the ultimate decision of how much protection should be bought for different loss scenarios based on different recurrence periods and intensity of events.

Another outstanding point is that the effect of the policy deductible becomes important especially in the analysis of the expected loss scenarios as the difference when applying the deductible to partial or total loss cases can be substantial whereas the likelihood of the behavior of the accumulation profile is yet to be determined for a justified PML analysis.

### THE TURKISH CATASTROPHE INSURANCE POOL AND BUILDING LOSS ESTIMATION FOR ISTANBUL – ID 2083

*E. Durukal, Bogazici University, Turkey*
*M. Erdik, Bogazici University, Turkey*
*K. Sesetyan, Bogazici University, Turkey*

In terms of national economy the insurance system is an essential element for the economic recovery of businesses, industry and families. The need for a paradigm change was clearly realized

by all parties involved following the 1999 Turkey earthquakes that caused substantial direct and indirect losses. In this context the Turkish government established the national earthquake insurance program, reinsurance companies reduced their risks by increasing their premiums or by even leaving the market and the private sector companies decided to re-asssess their portfolio risks in order to shape their future market strategies. Currently there is a two-level earthquake insurance system in Turkey. Level 1 is the compulsory earthquake insurance and level 2 is private insurance. Both for both systems the premium rates are set by the government. In this talk the current system will be described. Potential difficulties that may be faced by the actors involved at the national and local level in the event of a large earthquake in Istanbul will be highlighted with the help of an earthquake loss assessment methodology that can be used for insurance pricing and portfolio loss estimation in Turkey. The basic ingredients of this methodology are probabilistic and deterministic regional site dependent earthquake hazard, regional building inventory (and/or portfolio), building vulnerabilities associated with typical construction systems in Turkey and estimations of building replacement costs for different damage levels. Probable maximum and average annualized losses are estimated as the result of analysis. The effect of the two-level earthquake insurance system in Turkey (the national compulsory earthquake insurance scheme and the private earthquake insurance system) is incorporated in the methodology. As a demonstration of the methodology we look at the case of Istanbul and use its building inventory data instead of a portfolio. A state-of-the-art time dependent earthquake hazard model that portrays the increased earthquake expectancies in Istanbul is used. Intensity and spectral displacement based vulnerability relationships are incorporated in the analysis. In particular we look at the uncertainty in the loss estimations that arise from the vulnerability relationships, and at the effect of the implemented repair cost ratios.

### SEISMIC HAZARD AND RISK IN SHANGHAI AND ESTIMATION OF EXPECTED BUILDING LOSSES – ID 1715

*S. Cole, University of East Anglia, UK*
*Y. Xu, University of East Anglia, UK*
*P. Burton, University of East Anglia, UK*
*C. Cai, Shanghai Bureau of Seismology, China*
*W. Wang, Shanghai Bureau of Seismology, China*
*Y. Yin, Shanghai Bureau of Seismology, China*

Shanghai is a mega-city on the eastern seaboard of China with a population of over 13 million. Today it has become China's leading economic and business centre. Pudong New area, established in 1990, is at the forefront of Shanghai's modernisation. A seismic hazard analysis of Shanghai and neighbouring region has been determined. Peak ground acceleration, magnitude and intensity hazard are evaluated using Gumbel's extreme distributions. Cumulative strain energy release provides a graphical method of determining the annual energy release and 'maximum credible' earthquake. Expected building losses have been mapped in GIS for a section of Pudong together with two other areas of Shanghai named Putuo and Nanjing Road. A total of 791 buildings are included in the survey. Seven building types were used to divide the stock data and four damage grades were used in assessing potential damage. Analysis of damage curves is used to define the Mean Damage Factor which shows mean damage probability for various intensities for the varying building types. Results show the most vulnerable buildings are old civil houses and the least vulnerable are reinforced concrete frame and super high buildings. This data can be used to estimate potential building loss in terms of floor area and associated damage grade. Contacts: s.cole@uea.ac.uk

### NEW TRENDS IN VULNERABILITY ANALYSIS FOR UPDATING INSURANCE IN PORTUGAL – ID 878

*C. S. Oliveira, Instituto Superior Técnico, Portugal*
*A. Campos Costa, National Laboratory for Civil Engineering, Portugal*
*M. L. Sousa, National Laboratory for Civil Engineering, Portugal*

Insurance premiums in Portugal for earthquake incidence were established based on a study made in the mid 1990s. This study took into consideration the existing hazard modeling for the country and a classification of the housing stock into several typologies essentially parameterized by age of construction and number of stories. A mixture of Tiedemann, and Coburn and Spence vulnerability methodologies were developed based on the assignment of a Seismic Coefficient to each typology which depend on the seismic code in practice at the epoch of construction of that typology. Since that time, a few new approaches to vulnerability were developed, grouped into two main categories: one based directly on empirical data gathered in recent earthquakes; and the other making use of the principles of structural analysis, and essentially applying non-linear performance based displacements models. The present paper presents the new trends in vulnerability analysis developed in Portugal and how they can affect the results obtained a decade ago.

## SS 2-IV: Earthquake Loss Modelling : From Earth Sciences to Insurance Applications

Tuesday 17:15 - 18:15 – Room 3

### FEASIBILITY STUDY ON SEISMIC RISK SWAP USING PURE PARAMETRIC TRIGGERS FOR BUSINESS CONTINUITY – ID 800

*S. Fukushima, Tokyo Electric Power Services Co., Ltd., Japan*
*H. Yashiro, Tokio Marine & Nichido Risk Consulting Co., Lt, Japan*

Recently, some seismic risk management measures are utilized reflecting the quantitative and qualitative assessment of seismic risk. These measures are categorized into risk control and risk financing; the former is essential to mitigate seismic risk and the latter is effective to cover the unexpected loss caused by unforeseeable and complicated seismic events. In this paper, a seismic risk swap using pure parametric triggers is employed as a risk financing measure, so that the rapid and cost beneficial recovery plan can be achieved. Portfolios consisting of 50 facilities in Tokyo, Osaka and Fukuoka are employed as model enterprises in order to examine the feasibility of seismic risk swap assuming that the exchanged annual expected losses are identical. Through the examination, it is also proposed the procedure to determine the parameters used in parametric trigger based risk swap, from the viewpoint of reduction in probabilistic maximum loss.

### DEVELOPING A MICRO-ECONOMIC APPROACH FOR ESTIMATING INDIRECT LOSSES OF DISASTERS – ID 688

*D. Borst, Universität Karlsruhe (TH), CEDIM, Germany*
*U. Werner, Universität Karlsruhe (TH), CEDIM, Germany*

Within the CEDIM research on "current and future earthquake risk in Metropolitan Istanbul" this project focuses on economic aspects. It aims at developing a methodology to forecast financial losses caused by indirect economic effects of a disaster useful for a comprehensive risk assessment, thus enabling policy makers to optimise their financial strategies for prevention.

The paper explains in detail the working plan and progress of a micro-economic approach of loss assessment. As a basis for the rest of the work, input scenarios of direct losses due to an earthquake disaster have to be defined. Then, the current and future economic structure of the city is examined: Key economic sectors with respect to their importance in terms of employment and supply of goods essential for the Metropolitan community are identified. In a next step, representative units of critical sectors are selected by the use of local secondary data. This leads to a detailed analysis of their business models which are checked especially regarding to their vulnerability to possible disruptions after an

earthquake. Disruptions might be caused by broken physical linkages (e.g. interrupted supply of goods), by deterioration of public infrastructure (such as information systems) or by loss of key economic agents. Central to the project is a model of interlinked economic units which incorporates the spreading of indirect effects as a function of the changes of the supply of input goods, of direct damages at key economic nodes themselves (e.g. air- and seaports), and of possible declines of sales markets as another obstacle hindering economic prosperity. The results are then scaled up from certain sectors to the Metropolitan economy e.g. using input-output-tables. Finally, the model is calibrated for historical events.

### PROBABILISTIC HOLISTIC SEISMIC RISK ASSESSMENT METHODOLOGY FOR INDUSTRIAL FACILITIES – ID 2028

*K. Nasserasadi, IIEES, Iran (Islamic Republic Of)*
*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iran (Islamic Republic Of)*
*M. R. Zolfaghari, Khajeh nasir tousi UN., Iran (Islamic Republic Of)*

A methodology for estimation of holistic perspective of earthquake impacts on industrial facilities aimed to use the results in the mitigation programs is introduced in this paper. The methodology is divided to two main modules: estimation of direct impacts and estimation of indirect and macroeconomic impacts.

In the direct module, the direct impact of earthquake on equipments, structures and pipes are estimated in probabilistic manner. Based on direct impacts, the reliability of plants, probability of sequential effects and secondary hazard like fire, flood and explosion are estimated. A probabilistic method for estimation of damage effect of secondary hazards' consequence is developed. The probability of equipments' damage is estimated by aggregating the probability of damages to earthquake hazard and secondary hazards. The aggregated probability of damages is then used for estimation of probability of direct economical losses and reconstruction time.

In the indirect module, the indirect economic impacts as well as macroeconomic losses are estimated. The data of direct impact of earthquake which is estimated in the previous module is fed to indirect module in addition to some more information about the society and dependency of factory to that. The revenue loss of factory is estimated as a result of factory's recovery period. The macroeconomic impact is then estimated based on available information and input-output model.

The method has been applied to an oil refinery as case study. Here are some remarkable results. The secondary hazards have significant effect on damage of equipment and direct losses as well. The indirect and macro economic losses are substantial grater than the direct one. Parameter study has shown that the uncertainty of hazard cure is significantly contributed on the uncertainty of results. The recovery of household and dependency of factory to that is significantly contribute on the indirect loss of factory.

### A STUDY ON THE EARTHQUAKE RISKS ASSOCIATED WITH THE AUTOMOTIVE INDUSTRY IN THE MARMARA REGION – ID 1139

*Ö. Üçer, Bogazici University, Kandilli Earthquake Research, Turkey*
*E. Durukal, Bogazici University, Kandilli Earthquake Research, Turkey*
*M. Erdik, Bogazici University, Kandilli Earthquake Research, Turkey*

The Marmara region is home to 75% of the automotive-production facilities in Turkey. In the light of the damages sustained by the automotive sector in the 1999 Kocaeli earthquake and the very high probability of occurrence of a large earthquake (which stands at about 65% during the coming 30 years) makes it imperative that certain preparedness procedures be contrived in the event of and prior to an earthquake disaster, which in turn requires the quantification of effects of the earthquake on the automotive sector. With the endorsement and support of the Turkish Association of Automotive Manufacturers, eleven automotive manufacturing facilities located in the Marmara Region were visited including Ford, Toyota, Honda, Daimler-Chrysler, Fiat, Renault and Hyundai. Questionnaires designed to document the structural properties, non-structural equipment details, peripheral units (power, supplier, etc.), past earthquake damages and business losses assisted in the acquisition of homogeneous and concerted data. Meetings were held with the constructor firms and insurance professionals involved in the retrofit designs of damaged facilities and in the insurance claim processing after the 1999 earthquake. Earthquake performance and vulnerability issues were discussed with the manufacturers of critical machine, robots and equipment and concerned reinsurance/risk managers. Typical damage and loss figures concerning buildings, machinery, equipment and stock, and time-to-normal-operation could be estimated only for the EMS high intensity zones (VIII an IX) since the damages and losses were completely reported only in these intensity. Issues regarding the structure of the earthquake-insurance used by the sector were elaborated together with its performance in covering the losses in the 1999 Kocaeli earthquake. Finally projections regarding the possible losses that may be experienced by the automotive sector in the event of a large earthquake in the Marmara are presented. The consequences of these losses as well mitigation proposals are discussed.

## SS 3-I: Education and Outreach for Risk Reduction

Thursday 10:45 - 12:15 – Room 7+8

### REGIONAL DIFFERENCES IN TSUNAMI RISK PERCEPTION - A COMPARATIVE STUDY – ID 78

*T. Kurita, Asian Disaster Reduction Center, Japan*
*S. Colombage, Kobe University, Japan*

1. Objective The 2004 Indian Ocean Tsunami caused more than 300,000 casualties and almost 1.2 million affected people. It is considered that lack of knowledge about tsunami caused such damage, since tsunamis are infrequent in this area.

Authors carried out a questionnaire survey on tsunami awareness in Sri Lanka and the Maldives on the scale of 2,000 samples. The primary purpose of the survey is to assess and evaluate situations and community's capacity to respond to natural disasters.

2. Research Method Basically the survey focused on two categories of sample groups and different methodologies have been adopted to collect data from distinctive target groups as follows. - Residents: Questionnaires followed completely by an interview - Government officers: Questionnaires filled independently by respondents themselves

3. Results and Conclusions A careful consideration has given to the differences in social and cultural backgrounds throughout the study especially when analyzing results quantitatively and interpreting the implications. The authors could reach following conclusions.

- The overall trend shows that there is no significant difference between Sri Lanka and the Maldives. Following the common perceptions observed are: lack of prior awareness on tsunami disasters, dire need for disaster education in schools, necessity of effective countermeasure for tourists, and necessity of having evacuation drills together with government and community involvement.

- Residents in Sri Lanka who live near the shorelines, where the damage is relatively severe, do not have any intension to stay at same places in the future, while most of people in the Maldives want to inhabit same places. It is considered that this result reveals a reflection of national character, since the land of the Maldives is limited.

- In the Maldives, government officials in the Island Offices have similar thought with residents on evacuation place and countermeasures against natural disasters compared to the central government officials.

### CAPACITY BUILDING FOR EARTHQUAKE SAFETY AND MITIGATION THROUGH AWARENESS AND COMMUNITY EDUCATION – ID 722

*P. Barooah, Jorhat Engineering College, India*

The Indian subcontinent is highly prone to natural disasters like floods, draughts, cyclones and earthquakes. Disaster risk management is essentially a development problem and thus any preparedness and mitigation planning has to be taken up in tandem with environmental concerns that the country is facing today. The North East India is highly vulnerable to earthquake risk with the occurrence of two major devastating earthquakes of the world (1897 and 1950). From the periodicity of the earthquakes, a major earthquake is due at any time for which preparedness for mitigation of such a disaster is of topmost priority. The awareness regarding earthquake risk and its mitigation has to be taken to the people at various levels from professionals to the laymen. Special groups such as women, disabled persons, children etc. are more vulnerable in an emergency situation and hence require special attention. Several earthquakes show that women are usually worse affected than men when the disaster strikes. The women are not only victims; but also agents of change and women and men working together can identify the hazards that are threats to their homes and livelihoods and can work together to build safer communities. A study has been made in the urban, semi-urban and rural areas of Jorhat district, Assam aiming at strengthening capacities of these groups to respond to disasters. Special training methods, training manuals together with audio-visual aids are prepared and provided to women for enhancement of their capacities to carry out the activities effectively. Capacity building of women groups includes skill up gradation in use of the latest know how for effective response and sustainable recovery in earthquake disaster situations. The results of this study are highly encouraging in enhancing the capacity of women in first aid, Water and Sanitation, Shelter management and Rescue and Evacuation.

### FRENCH SCHOOLS SEISMIC SAFETY, BUILDINGS AND USERS PREPAREDNESS IN FORT DE FRANCE AND GRENOBLE AREAS – ID 2050

*S. Cartier, CNRS, France*
*L. Colbeau-Justin, France*

Earthquake safety in schools is a practical and symbolic aim. Schools concentrate vulnerable population and are dramatically stroke. School buildings are also refuge places after shakes. Schools represent cohesion between generations in community life.

The LGIT is studying school buildings. The social sciences approach analyzes anti-seismic investment of school owners and preparedness of people using it. Based on sociological, psychological and geographic skills, the team explore two French sites located in seismic areas : Fort de France and Grenoble.

For each case, safety mobilize enough attention to be welcome among local administrations, which accept to explain responsibilities, fears and responses to reduce vulnerability. High seismic activity and exposure to natural treats in Martinique induce a better people awareness. In Grenoble area, seismic preoccupation is lower than industrial fear and keeps more as an administrative awareness. In both sites, there is a difficulty to clarify liabilities and means to prepare school users. Schools have often been built before anti-seismic codes. Only new schools and restructured ones are retrofeated. Reinforce old buildings would be difficult for technical and financial reasons. In spite of administrative documents, actually safety training is very low, because of lake of information, lake of time and difficulties to know responsibilities repartition. If the natural seismic exposition is different for each population, both share difficulties to manage competences, to find money to retrofit buildings and to train users. Falling within the competence of local authorities, safety investment is to heavy and long term to forget users training. But, the complexity of liabilities according to buildings and moments avoid the clarification of coordination and training of different school users.

### "TUTTI GIU' PER TERRA" (ALL FALL DOWN) - AN ACTIVE COURSE TO DISCOVER EARTHQUAKES TOPICS – ID 1390

*R. Camassi, INGV, Italy*
*F. Brasini, ConUnGioco, Italy*
*D. Modonesi, ConUnGioco, Italy*
*B. Sidoti, ConUnGioco, Italy*

Teaching topics involving risk and safety, and earthquake, requires a full involvement. Otherwise, it can be useless. A full involvement means an experience rewarding the person in his/her integrity, starting from practice to go beyond it, understanding phaenomena not using science as a form of rational believe, working on the different ingenuous idea that everyone has of the earthquake, staying related to the social connections of the learning group. ConUnGioco developed, starting from these objectives, "Tutti giù per terra", an active course for discover, for the italian INGV: the course, whose title is inspired to the last line ("All fall down", in italian, "Tutti giù per terra") of the child singing game "Ring a ring'o roses" (in italian: girotondo), is based on an interactive and partecipative approach. Following the active course, partecipants can experiment feeling and emotions related to the experience of an earthquake (through simulation tools); therefore, starting from the questions that the simulated experience raised in everyone, the group will search its own answers, investigating theorical knowledges with scientific experiments and games, staying in touch with explanations coming from legends, history and religion; the course will end in the area of concrete actions and possible reactions to an earthquake, talking about preventions and solutions, individually and as a community.

### THE COMIC, A HIGH IMPACT AND EFFECTIVENESS DIVULGATION MEDIA FOR BASIC SEISMIC ENGINEERING LEARNING – ID 1401

*R. Arroyo Matus, Universidad Autonoma de Guerrero, Mexico*
*R. Iglesias Segrera, Universidad Aut{onoma de Guerero, Mexico*

In order to spread the state-of-art of earthquake engineering through a high impact and penetration communication media among non specialized people -principally children-, in this paper the book “Look how I'm shaking” is presented. General seismology, basic principles to know if our home possesses earthquake-resistant characteristics as well as basic civil protection preparedness measurements are described in this free-distributed comic-book. Obtained statical results after the book's distribution shown that comics allow more significant understanding of seismic aspects as well as the reflective understanding on mitigation tasks of the earthquake's correlated effects.

## SS 3-II: Education and Outreach for Risk Reduction

Thursday 13:30 - 15:00 – Room 7+8

### TOWARDS A SUSTAINABLE EARTHQUAKE ENGINEERING EDUCATION SYSTEM IN EGYPT – ID 1340

*M. Sobaih, Faculty of Engineering, Cairo University, Egypt*

The current status of earthquake engineering is still limited in spite of the recently remarkable earthquakes in Egypt and the efforts done by the Egyptian Society for Earthquake Engineering which is a NGO. Few years ago the Ministry of Education has created the Higher Education Enhancement Fund ( HEEPF) funded by the International Bank to help in enhancing the education system in Egypt. The Faculty of Engineering at Cairo University in collaboration with the Egyptian Society for Earthquake Engineering has succeeded to obtain a funded project within the framework of HEEPF. The project entitled ' Enhancing Earthquake Engineering Education' lasts for two years starting mid-july 2005. It aims at enhancing earthquake engineering

education on both the undergraduate and graduate levels. This will be achieved by developing five courses and activating a Higher Diploma in Earthquake Engineering. To create a base for education resources a series of activities will be made. A specialized library will be created including all published research done in Egypt. It also includes some of the most recent references, textbooks and proceedings of international conferences. A focal point will be created containing data about active Egyptian researchers in the field. This will enable them to communicate and disseminate information with each other. The experimental facilities at the Faculty of Engineering, Cairo University will be upgraded. Besides, a virtual learning unit will be established.

It is expected that the project will have a great impact on upgrading the education in the field of earthquake engineering in all Egyptian Universities.

### WEBSISMO: INTERACTIVE WEB SITE FOR EDUCATION AND PUBLIC AWARENESS ON EARTHQUAKES AND SEISMIC RISK – ID 1777

*M. J. Jimenez, Institute of Earth Sciences "Jaume Almera"-CSIC, Spain*
*M. Garcia-Fernandez, Institute of Earth Sciences "Jaume Almera"-CSIC, Spain*
*E. Rubio, Institute of Earth Sciences "Jaume Almera"-CSIC, Spain*
*M. Gomez, GEOMEDIA, Spain*

The WEBSISMO is a combined scientific, technical and educational project which is part of the established cooperation between several institutions in Spain and is funded by the Spanish Ministry of Education and Science. WEBSISMO aims to develop an interactive web site for educational purposes as well as to increase public awareness on earthquakes and seismic risk.

The web site consists of a virtual community which is affected by seismic events of different characteristics. Based on the elements of the community (public or private buildings, structures, lifelines, landscape elements, etc) a number of seismic scenarios can be generated. The elements in the community constitute links to a number of didactic units allowing the user: 1) to understand the origin of earthquakes; 2) to directly observe earthquake effects in buildings and lifelines with a wide range of vulnerabilities; and 3) to be aware of the proper measures to prevent and mitigate earthquake effects. Furthermore, the web site will include the access to updated technical documentation on building codes, microzonation for municipalities and emergency response plans. The concept of WEBSISMO is based on an open architecture that will further allow to adapt or modify specific aspects tailored to the needs of the potential hosting public or private institutions.

The chosen media, the Internet, provides one of the most effective ways at present to share knowledge and insights from earthquakes studies and other research that is needed by the community before, during, and after a damaging earthquake to mitigate seismic risk.

WEBSISMO project is been developed at the Institute of Earth Sciences "Jaume Almera", in close cooperation with external outreach professionals (GEOMEDIA). The web will be implemented and tested as a pilot experience also at the University of Madrid, at the University of Alicante, at the National Geographical Institute, at Spanish Civil Defence.

### EDUCATING THE PUBLIC IN THE CENTRE SEISMOPOLIS: THE EARTHQUAKE SIMULATOR – ID 2031

*V. Kouskouna, University of Athens, Greece*
*G. Giouvanelli, University of Athens, Greece*
*G. Papadokotsolis, University of Athens, Greece*
*G. Sakkas, University of Athens, Greece*
*N. Sakellariou, University of Athens, Greece*
*K. Vasilakou, University of Athens, Greece*
*N. Voutsas, University of Athens, Greece*
*I. Zamba, University of Athens, Greece*

Within the educational centre SEISMOPOLIS (Athens, Greece), the earthquake simulation area consists of a separate room, within which the shake table has been transformed into a typical kitchen. A special warning notice has been erected in cases of medical emergency, and security measures have been taken at the entrance, exit and around the shake table. Prior to the earthquake simulation, visitors will have attended a presentation on the earthquake phenomenon and the measures and actions that ought to be taken before, during and after an earthquake. The experience on the shake table aims at the familiarization of the public with the earthquake shaking. Table drive motion is provided by a PC based LabView virtual instrument called "Poseidon". Two members of the staff (postgraduates in Seismology) are present during the demonstration: the operator who enters the input earthquake data, and the instructor who is present on the shake table. The visitors enter the earthquake simulator room in groups of up to 12 people, including their guide and the instructor. The instructor's briefing is modified according to the type of visitors concerned (e.g. school children, adults, the elderly, persons with special needs, etc.). During this briefing, the shaking is experienced without prior warning, but with a running commentary by the instructor.

### EARTHQUAKES AND GHOST TOWNS IN SICILY (SOUTHERN ITALY): A JOURNEY THROUGH THE PLACES OF MEMORY. A PROPOSAL OF VIRTUAL SEISMIC ITINERARIES AS AN EDUCATIONAL TOOL – ID 2047

*R. Azzaro, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*R. Camassi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*M. Cascone, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*L. Peruzza, Istituto Nazionale di Oceanografia e Geofisica Spe, Italy*
*A. Amantia, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*F. Guglielmino, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. Mangiagli, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

In the framework of the EDURISK Project (Earthquake eDUcation: a journey for seismic RISK reduction), we have developed an innovative multimedia product inspired by the most traumatic effect of a seismic catastrophe, namely the abandonment of inhabited centres. This situation represents an event of wide historical, cultural and anthropological impact because it determines the loss of a piece of history and culture; at the same time it witnesses the fragility of the territory with respect to earthquakes. The rediscovery and re-evaluation of localities abandoned following earthquakes is therefore a unique opportunity from a cultural standpoint when dealing with earthquake education strategies, enhancing the awareness of seismic risk as an element of daily life. Following this guideline, we have published the first DVD-Rom for a virtual seismic itinerary through Sicily, to visit 17 localities destroyed by the 1693, 1783 and 1968 earthquakes. The DVD has been issued in two versions: full, in italian and "export", in english. Different kinds of materials have been collected and merged together in order to fully explain the seismic history of the selected archaeological sites: images documenting how they appeared in the past and their present status, historical documents accounting for the effects of earthquakes as well as for subsequent social impact associated with reconstruction dynamics, information on the earthquakes and the seismic classification of the territory. The interactive technique adopted for virtually exploring and navigating throughout the abandoned sites is the Quick Time$^{TM}$ Virtual Reality format (QTVR). The user can select three thematic journeys: space (i.e. the territory seen through the images), time (the memory recovered through historical documents) and seismicity (i.e. the natural cause). Each path presents and links together the different kinds of material (reports, chronicles, maps, pictures and videos) contained in the DVD, giving more emphasis to a particular aspect.

## SS 4-I: ESC-UNESCO Workshop on Earthquake Hazard and Seismic Risk Reduction : Studies in the Southern Mediterranean Countries

Monday 15:30 - 17:00 – Room 3

### ASSESSMENT OF SEISMIC HAZARD IN JORDAN – ID 226

*M. Jimenez, Institute of Earth Sciences "Jaume Almera", Spain*
*H. Al-Nimry, Royal Scientific Society, Jordan*
*A. Khasawneh, Royal Scientific Society, Jordan*
*T. Al-Hadid, Royal Scientific Society, Jordan*
*K. Kahhaleh, Royal Scientific Society, Jordan*

Probabilistic hazard maps for Jordan are developed using a homogeneous probabilistic seismic hazard assessment. The resulting maps quantify seismic hazard in terms of peak ground acceleration, PGA, and of spectral acceleration, SA, (at 0.1, 0.2, 0.3, 0.5, 1.0 and 2.0 seconds) for a probability of exceedence of 10% in 50 years for rock sites. The study area is divided into 18 discrete homogeneous seismic sources and the seismic parameters are assigned accordingly. The ground motion attenuation models developed by Ambraseys et al. (1996) in terms of PGA and SA are chosen to relate the expected ground motion at a site with the magnitude and distance of the earthquake. Using SEISRISK III to carry out the hazard computations, and assuming that earthquake occurrences follow a Poisson distribution, the probabilities that any acceleration value is exceeded are determined by integration over all seismic sources. To provide engineers with appropriate design tools, the resulting spectral acceleration values are used to develop a macrozonation map for Jordan as well as the corresponding response spectra.

### EVALUATION OF SEISMIC HAZARD IN ALGIERS USING DIFFERENT ATTENUATION MODELS – ID 1579

*D. Benouar, usthb, Algeria*
*M. Naili, USTHB, Algeria*

This research work presents the evaluation of seismic hazard at the site of Algiers (Capital of Algeria) using four different attenuation models. Seismic hazard analysis was carried out using a simple earthquake occurrence model and the new seismic catalogue compiled recently by Benouar in 1993 for the Maghreb region. The site is defined by longitude 3.00°E and latitude 36.45°N. Because earthquake process around the site is poorly understood, it is assumed that future earthquakes will occur in an area in which they have already occurred in the past. The hazard, expressed in terms of the probability of exceedance of the PGA, is calculated for an economic life of the structure of 10, 50, and 100 years. The absolute acceleration for a given return period is also determined. Due to the shortage of ground motion records, no attenuation law has been derived for Algeria. The main objective of this study is to analyse the influence of the attenuation models on the seismic hazard evaluation, since the results of seismic hazard are sensitive to these models. Thus, a selection of an appropriate attenuation law is very crucial. For this purpose, four attenuation laws which seem to fit the Algerian data were selected from the literature, these are Joyner and Boore, Ambraseys and Bommer, Ambraseys (controlled depth) and Ambraseys (uncontrolled depth). A comparison of the expected seismic hazard allows a first critical estimate showing that seismic hazard is very sensitive to the attenuation models selected and the PGA could be either conservative or not, depending on the attenuation model and the level of acceptable risk. And also it shows that the Algiers-Boumerdes earthquake of May 21st, 2003 has changed completely the seismic hazard assessment in the region considered.

### COMPLETENESS AND SCALING RELATIONS FOR THE EARTHQUAKE CATALOGUE OF EGYPT – ID 1837

*H. Hussein, NRIAG, Egypt*
*E. Abu El-Nader, NRIAG, Egypt*
*I. Korrat, NRIAG, Egypt*
*K. Abou Elenean, NRIAG, Egypt*
*I. Marzouk, NRIAG, Egypt*
*M. Elgabry, NRIAG, Egypt*

The idea of this work comes from our need to construct an updated catalogue for the instrumentally recorded earthquakes in Egypt with uniform and homogenous source parameters sufficient for qualitative and quantitative studies. This in turn require more detailed analysis and comparison of all entries, including, the distribution of events with time, the completeness of catalogue and the scaling relations between different kinds of magnitudes reported by different agencies in order to find the rules necessary for the magnitude priority choice. The observational data covers the time interval 1900-1998. The data considered in this analysis lies between 25E to 35.5E and 22N to 34N. Analysis of the various magnitudes indicates that the catalogue can be considered complete for MD (HLW)4 since 1985, MD (RYD) 3.5 since 1985, ML(IPRG) 3 since 1985 and mb (ISC)5 up to 1998. The scaling laws between different kinds of magnitude scales in different time periods and with different magnitude ranges indicate that the most superior relations are the log Mo with ML , MD(HLW) MD(RYD) and ML(IPRG) MD(HLW). Linear regression of the binned data set was also performed for the individual data points which show large scatter. The linear regression analysis for the binned data set show that ML(IPRG) vs mb (ISC) and ML(IPRG) vs MD(RYD) give a relatively good regression results

### ASSESSMENT OF SITE SPECIFIC EARTHQUAKE HAZARDS IN URBAN AREAS IN ISRAEL – ID 1602

*Y. Zaslavsky, Geophysical Institute of Israel, Israel*
*A. Shapira, International seismological Centre, UK*
*M. Gorstein, Geophysical Institute of Israel, Israel*
*P. Nahum, Geophysical Institute of Israel, Israel*

In the last 10 years the geophysical Institute of Israel has launched a number of projects to determine and map seismic site response characteristics across Israel. These investigations are part of microzonation mapping of the seismic hazard in urban areas across Israel. We used horizontal-to-vertical (H/V) spectral ratios obtained from ambient vibration measurements together with available geological, geophysical and geotechnical information to construct a subsurface models for the investigated sites. These models, in turn were used to determine, analytically, the expected site response to seismic shear waves. Since seismic activity in areas such as Israel is low, local acceleration data from strong earthquakes are insufficient to estimate directly the design acceleration spectrum; therefore, in areas covered by soft sediments, site specific earthquake hazard estimation is based on simulations of the regional seismic activity and on synthetic accelerograms, generated by implementing stochastic methods. In recent years, seismic microzonation studies were carried out in the Israeli towns Lod Ramle, Qiryat Shemona, Kefar Sava, Dimona, Arad, Bet Shean, Afula, Qiryat Haim, Qiryat Bialik and Qiryat Mozkin. These studies suggest amplification effects in the frequency band 0.5-14 Hz, some of which may reach a factor of 10. Based on the observed resonance frequencies, their corresponding spectral ratio amplitudes and shape of the H/V curves, we divided each town into zones. Within each zone we chose randomly 10-15 locations, each providing a 1-D subsurface model, to assess the Uniform Hazard Acceleration Response Spectrum from which we designed, for each zone, a representative Acceleration Response Spectrum for a uniform hazard ecxceedence probability of 10% in an exposure time of 50 years and a damping ratio of 5%. These Spectra across the investigated areas suggest that allowances made in the Israeli Seismic Code for soft soil conditions should be carefully re-examined.

### PSHA FOR THE BROADER TBILISI TEST AREA – ID 1831

*D. Slejko, OGS, Italy*
*A. Rebez, OGS, Italy*
*M. Santulin, OGS, Italy*
*Z. Javakhishvili, Institute of Geophysics, Georgia*
*M. Elashvili, Institute of Geophysics, Georgia*
*J. Garcia Pelaez, Centro Nac. Invest. Sismologicas, Cuba*

The Caucasus region is well known for its high seismicity and strong earthquakes occurred also recently (magnitude 7.3 in 1991 and 6.8 in 1992) causing deaths and widespread damage. It was one of the test areas of the Global Seismic Hazard Assessment Project (GSHAP) developed between 1993 and 1999 which aimed at constructing the global seismic hazard map of our planet. The SETA (SEismic hazard assessment for the Tbilisi test Area) project is a co-operation project supported by the Italian Government. Aim of the project is the seismic hazard assessment of the Tbilisi broader region. The GSHAP project has focused the different ideas existing about the seismogenesis in the Caucasus. To take into proper account for those different hypotheses, it was decided to use a logic tree structure in the SETA project. This logic tree consists of 2 seismogenic zonations, 2 methods for the seismic rate computation, 2 approaches for the maximum magnitude (Mmax) determination, and 3 attenuation models. The first seismogenic zonation is the main one used in the GSHAP projects, the second one is the most recent seismogenic model presently available for the region with 4 alternative hypotheses of fault activation. The seismicity rates were computed according to two statistical ways, both used in recent Italian hazard maps. Mmax is computed according to a statistical approach and following a geological method. The first attenuation model for peak ground acceleration (PGA) was calibrated on European earthquakes, the second on Caucasian earthquakes, and the third is defined in the framework of the SETA project and considers only Georgian events. The PSHA of the Tbilisi broader area has been performed according to the Cornell approach. The PGA hazard estimates refer to a 475-year return period, standard reference in seismic design.

### SEISMIC HAZARD ASSESSMENT FOR THE ITALIAN TERRITORY IN TERMS OF MACROSEISMIC INTENSITY – ID 1947

*A. A. Gomez Capera, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*C. Meletti, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Rebez, Ist. Naz. di Oceanografia e di Geofisica Sperim., Italy*
*M. Stucchi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

A seismic hazard assessment in terms of macroseismic intensity is proposed for the Italian territory and for different probabilities of exceedance. The input elements used to assess the seismic hazard are: the seismogenic zoning ZS9, the earthquake catalogue CPTI04, the historical and statistical completeness time intervals, seismicity rates in terms of epicentral intensity (Io), varied attenuation models as function of epicentral distance. The first three elements were taken from the national seismic hazard reference map released in 2004, while the other two are proposed in the present work and literature. In particular, one of the alternative intensity attenuation model has been defined in this study based on the updated Italian macroseismic database, and includes different relationships: i) one valid for the whole Italian territory; ii) a set of relations that account for different predominant focal mechanism in the seismogenic zones, including one specific relation for the Etna volcanic zone. A logic tree approach allowed to explore some possible alternatives of epistemic character, with regard to completeness, seismicity rates evaluation modalities and attenuation model. The computer code adopted to evaluate the seismic hazard, with the elements cited above, is SeisRisk III, which has been modified to be used with macroseismic intensity data, i.e. allowing to consider the normal distribution of the residuals. Finally, a tentative comparison with the results obtained in terms of PGA is presented, obtained by making use of available intensity/acceleration relationships.

## SS 4-II: ESC-UNESCO Workshop on Earthquake Hazard and Seismic Risk Reduction : Studies in the Southern Mediterranean Countries

Monday 17:15 - 19:00 – Room 3

### PRELIMINARY RESULTS OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT IN THE VOLCANIC REGION OF MT. ETNA (SOUTHERN ITALY) – ID 1931

*R. Azzaro, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. D'Amico, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*T. Tuvè, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*D. Albarello, Dip. di Scienze della Terra, Università di Siena, Italy*
*M. S. Barbano, Dip. di Scienze Geologiche, Università di Catania, Italy*
*V. D'Amico, Dip. di Scienze della Terra, Università di Siena, Italy*

A detailed analysis of Probabilistic Seismic Hazard Assessment (PSHA) applied to the Mt. Etna region, is presented. This area, like other active volcanic districts worldwide, is characterised by very frequent earthquakes locally producing severe damage-destruction (epicentral intensity up to X EMS-98) but associated with low values of magnitude and depth ($M \leq 4.8$, $H \leq 3$ km), and a high attenuation of macroseismic intensity with distance (decay of intensity equal to DI = 4 in the first 20 km). The PSHA has been performed in the framework of the S1 project funded by the Italian Civil Protection Department using an alternative approach to the standard one (i.e. Cornell method). It is based on the statistical analysis of site seismic histories in terms of macroseismic intensity I. Observed site data are integrated with values calculated by an attenuation law specific for the Etna region when documentary information about macroseismic effects is missing for some earthquakes. In the analysis, two different datasets are used: the parametric catalogue of the Italian earthquakes CPTI04 – the directory adopted in the compilation of the seismic hazard map MPS04 by INGV – and the macroseismic catalogue of Mt. Etna earthquakes. The comparison between PSHA obtained with a national attenuation law and those computed applying the attenuation law for the Etna region, shows that probability of occurrence and average return time for intensities VI-VIII EMS may significantly vary when a local catalogue with a greater number of events (with a lower energy threshold) is adopted. The seismic hazard map in terms of maximum intensity characterised by a 10% probability of exceeding in an exposure time of 50 years, is presented. Finally the intensities values are also converted in PGA values and PSHA results are compared with those obtained through the Cornell method.

### PRELIMINARY REPORT ON SEISMOLOGICAL AND STRONG MOTION DATA OF THE KYTHERA (GREECE) MW6.8 EARTHQUAKE OF JANUARY 8, 2006 – ID 2004

*C. Papaioannou, Inst. Engin. Seismology & Earthquake Engin., Greece*
*N. Theodulidis, Inst. Engin. Seismology & Earthquake Engin., Greece*
*A. Savvaidis, Inst. Engin. Seismology & Earthquake Engin., Greece*
*P. Dimitriu, Inst. Engin. Seismology & Earthquake Engin., Greece*
*B. Margaris, Inst. Engin. Seismology & Earthquake Engin., Greece*

On January 8, 2006 (11:34 GMT) a strong earthquake of magnitude Mw6.8, occurred in Southern Aegean Sea close to the island of Kythera in Greece. The epicenter coordinates were 36.16° N and 23.36° E and the focal depth 66 km. The earthquake was strongly felt in an extensive part of Greece as well as in Southern Italy, Egypt, Cyprus, Turkey, Israel, Lebanon, Syria and Jordan. The most serious damage were observed on rigid structures at

the Island of Kythera. Minor damage were also observed at the Prefecture of Chania (Crete Isl.). This earthquake was the first strong intermediate depth earthquake in the southern Aegean area with epicentre located close to the August 11, 1903 earthquake (M=7.2) epicentre. In the first part of the present paper is the analysis of the seismological data. Then the analysis of the available accelerometric data is shown. The stations used are distributed at epicentral distances 42-500 km and the recorded PGA values had values between 130-0.5mg. The results on the attenuation of the peak ground acceleration of this earthquake are compared with previous published empirical relations and discussed. The acceleration spectra of the strongest recorded acceleration time histories are compared with previous strong earthquakes in Greece and the result are discussed. An attempt is made for the compilation of the macroseismic field which is compared with the one of the 1903 earthquake.

### A SEISMIC RISK ANALYSIS IN THE MURCIA REGION (SE SPAIN). RISMUR PROJECT – ID 1754

*B. Benito, Universidad Politécnica de Madrid, Spain*
*P. Murphy, Architect COAM 12714, Spain*
*M. Tsige, Universidad Complutense de Madrid, Spain*
*J. J. Martínez-Díaz, Universidad Complutense de Madrid, Spain*
*M. E. Jiménez Peña, Universidad Politécnica de Madrid, Spain*
*M. J. García-Rodríguez, Universidad Politécnica de Madrid, Spain*
*J. M. Gaspar-Escribano, Universidad Politécnica de Madrid, Spain*
*J. García-Mayordomo, Universidad Politécnica de Madrid, Spain*

The Murcia Region is one of the most actives zones in Spain, where three recent earthquakes occurred recently. In spite of their low magnitudes these earthquakes caused important damages, reaching EMS98 intensities VI to VII. The RISMUR project aims at providing a general picture of the seismic risk, allowing the identification of zones requiring a more detailed analysis where prevention plans should be priorized. A multidisciplinary study has been carried out, involving the main aspects of the risk problem. In the first phase, a general study at regional scale has been carry out, starting with the seismic hazard assessment following the PSHA methodology, with a logic tree composed by two nodes: zonification and attenuation models. In a first step, the motion is predicted in generic rock sites. Additionally, a regional geotechnical study and a classification of eight types of soils have been proposed, with the corresponding amplification factors representing ground response to seismic shaking. The combination of the previous maps and factors, gives a new hazard map that includes local effects. In parallel, a vulnerability assessment of the building stock that distinguishes between rural and urban environments is carried out, based fundamentally on the construction age. In the definition of the vulnerability classes and damage degrees. Taking into account the expected ground motions and building vulnerabilities, the distribution of expected damage is estimated by the application of probability damage matrixes. Several damage indexes are defined, and relative and total damage estimates at each location are derived. With these data, a suite of maps representing seismic risk in terms of damage parameters for the entire Region have been obtained. The interpretation of the different maps allow us identify the locations with higher expected damage, where specific hazard and damages scenarios must be carried out in a second phase of the project.

### TIME-DEPENDENT SEISMIC HAZARD ASSESSMENT OF NORTH-EASTERN ITALY – ID 1857

*V. Montaldo, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*F. Galadini, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

The seismic hazard of North-Eastern Italy has been assessed using a probabilistic, hybrid approach where the occurrence of large earthquakes follows a renewal model while the smaller events are stationary in time. The source model adopted in this study includes seismogenic sources capable of generating strong earthquakes basically related to thrust faulting. The geometry of the sources has been defined through a multi-stepped procedure in which a preliminary framework of seismogenic sources potentially responsible for destructive earthquakes was defined based on the available surficial/sub-surficial data. Subsequently, the different seismogenic sources were better constrained on the basis of seismological information. Hypotheses have been made for the sources which generated earthquakes in the magnitude range 5.5-6.0, based on the comparison between the damage distribution and the structural framework related to the present tectonic regime. The result of this procedure are ten main seismogenic sources potentially responsible for earthquakes with M>=6, and five minor sources which may be responsible for events with M between 5 and 6. These seismogenic sources are assumed to have a characteristic behaviour in that the magnitude distribution is a truncated normal, while the occurrence of the characteristic events in time is represented by a lognormal distribution. The parameters controlling the distribution are: the time elapsed since the previous event, the slip rate and the characteristic magnitude. Two background areas accounting for small events are treated in a conventional probabilistic approach, i.e. a Gutenberg-Richter relation models the frequency of the earthquakes under the hypothesis stationary seismicity. The results of the analysis are maps of peak ground acceleration for probability of exceedance of 1 and 10% in the next 50 years. These maps are compared with available poissonian maps and deaggregation is performed at selected localities to show the different contribution of the seismogenic sources to the overall hazard.

### CONTRIBUTION TO SEISMIC HAZARD EVALUATION IN NORTHERN ALGERIA – ID 1106

*A. Abdelhakim, CRAAG, Algeria*

The Tellian Atlas, northern part of Algeria is known as on of the most seismic active area in the Mediterranean basin. Many have been reported to have occurred in different seismogenic zones, such as Mascara, Echeliff basin (former el Asnam), Mitidja basin (Algiers vicinity). On the basis of the available seismic data we have produced a map of maximum observed intensities which gives an overview of the hazard in the northern part of Algeria. We have also compiled the tectonic data from different geological studies to draw the tectonic map of northern Algeria. Intensity attenuation laws have been also established for specific regions where strong earthquakes occurred.

### THE LAALAM (BEJAIA, NORTHEAST ALGERIA) MODERATE EARTHQUAKE OF MARCH 20TH, 2006, ML:5.8 – ID 1968

*H. Beldjoudi, CRAAG, Algeria*
*A. Kherroubi, CRAAG, Algeria*
*A. Guemache, CRAAG, Algeria*
*F. Semmane, CRAAG, Algeria*
*A. Haned, CRAAG, Algeria*
*A. Yelles, CRAAG, Algeria*
*H. Djellit, CRAAG, Algeria*
*S. A. Haned, CRAAG, Algeria*
*A. Deramchi, CRAAG, Algeria*

On March 20th,2006 at 19h44mn, a moderate earthquake of Ml:5.8 hit the region of Laalam (Bejaia, Northeast Algeria). This event is the second moderate one which happened in the region after the Beni Ouartilane earthquake of November 10th,2000 (Ml:5.4). The earthquake occured in a region which is repeatedly shaken by events triggered by the Kherrata fault. The earthquake caused the death of 4 persons and the injuries of 175 persons. The epicenter was located at 36.55N 5.40E, close to the village of Laalam (Bejaia). In this region, between Kherrata and Bejaia, several buildings and private houses suffered from the event, some of them collapsed totally. The earthquake with an intensity of VII was largely felt by the population of the eastern region of Algeria. In the epicentral area, some minor breaks and rockfalls have been observed. According to the focal mechanism solution provided by the NEIC and the ETH seismological centers, the earthquake is associated with a sinistral fault with a NW-SE orientation. Few hours after the main schock, a seismological network of ten portable stations was deployed in the region to complete the coverage of

the National Seismological Network. From the afterschoks data analysis,the location of the data indicate a NW-SE trend of the fault. The Laalam earthquake expresses an activation of a branch of the major NE-SW Kherrata fault.

### POST ASTIAN ACTIVE FAULT ALONG THE SOUTHERN BORDER OF THE MITIDJA BASIN (NORTH CENTRAL ALGERIA) – ID 1958

*H. Djellit, CRAAG, Algeria*
*A. K. Yelles, CRAAG, Algeria*
*A. Abtout, CRAAG, Algeria*
*A. Guemache, CRAAG, Algeria*
*S. Gharbi, CRAAG, Algeria*

The Mitidja basin (north central Algeria) is characterized by an important seismic activity. In the past, several major earthquakes happened in this region (Algiers, 1365, 1716, Blida,1825...). The last important event occurred on May 21st 2003 in the region of Boumerdes located 50 km east of Algiers (the capital of Algeria). The seismic activity is generated by the two main faults system which borders the basin in its northern and southern part (Boudiaf,1996). Until now, these two faults system remains poorly studied mainly along the Blidean Atlas. The recent investigations that we carried along the southern border of the Mitidja basin allowed to reveal a fault segment located along the blidean massif in its south oriental limit. In this area, a fault is visible and is linked with post pliocene deformations. The fault expresses by a linear and continuous scarp with a length of 2 km the fault. Along the fault, sandstone levels are strongly deformed. This fault is related to a huge folding of the Pliocene formations with a hundred meters of width and extending along several kilometres. The fault with an orientation of NE-SW deepens towards the southeast with an angle of 50°-60°. These Pliocene deformations are obviously linked with a post astian tectonic. Study of the terraces located along both of the two flanks of the thrust fault with a height difference of 30 m indicates that the fault is active during the Quaternary period . Locally, the terraces are thrusted by the cretaceous units. Microtectonic studies indicate that this is an inverse fault with NW vergency.

# Poster Presentations - From Monday to Wednesday

## CS1: Seismic Input for Design (EC8 and Others)

Level-1

### SEISMIC HAZARD OF TEHRAN BASED ON SEISMIC REHABILITATION CODE FOR EXISTING BUILDINGS IN IRAN – ID 3

*G. Ghodrati Amiri, Iran University of Science & Technology, Iran (Islamic Republic Of)*
*S. A. Razavian Amrei, Iran University of Science & Technology, Iran (Islamic Republic Of)*

In this paper the results of a study were undertaken to determine the seismic hazard of Tehran based on seismic rehabilitation code for existing buildings in Iran. There are four values for hazard level in this code to evaluate the seismic performance of existing buildings. These hazard levels are 2%, 10%, 20% and 50% of probabilities of exceedance in 50 years of life time period. The output of the probabilistic seismic hazard analysis is based on peak ground acceleration (PGA), which is the most common criterion in designing of buildings. A catalogue of seismic events that includes both historical and instrumental events was developed and covering the period from 4th century BC to 2004 is used. The seismic sources that affect the hazard in Tehran were identified within the radius of 200 km and the recurrence relationships of these sources were generated by Kijko and Sellevoll [2000]. Finally four maps have been prepared to indicate the earthquake hazard of Tehran and its vicinity in the form of iso-acceleration contour lines for different hazard level by using SEISRISK III

### A SIMPLIFIED DEFORMATION-BASED SEISMIC VULNERABILITY ASSESSMENT APPROACH – ID 11

*M. Safar, McMaster University, Canada*
*A. Ghobarah, McMaster University, Canada*

Recent simplified vulnerability assessment studies have used displacement response spectra for describing earthquake ground motions, driven by the premise that a good correlation exists between displacement and damage. The use of response spectra presents a rather complete description for the ground motion compared to the use of single instrumental parameters or macroscopic intensity scales. In such studies, the capacity of a building class is defined by relating its deformation potential to its fundamental period of vibration at different limit states and comparing this with a displacement response spectrum representing the demand. However, the stress has been made in such studies on the derivation of the capacity curves. A new and rational method for constructing constant ductility response spectra (CDRS) based on constant yield displacement load-deformation model is presented. The merit of the proposed spectra is demonstrated through its utility in describing the seismic demand within a simplified vulnerability assessment procedure. Refinement is made for the derivation of the capacity curves for different limit states to match the concept adopted in developing the demand. Furthermore, final softening index is incorporated in the definition of various limit states.

### RELATIONSHIPS BETWEEN PGV AND RESPONSE SPECTRAL ORDINATES – ID 93

*J. Alarcon, Imperial College, UK*
*E. Booth, Consulting Engineer, UK*
*J. Bommer, Imperial College, UK*

Peak ground velocity (PGV) is widely recognised as one of the best simple predictors of damage and has been used for a variety of applications, including generation of structural vulnerability functions, construction of response spectra, study of buried pipelines and evaluation of liquefaction potential. PGV has also been used in conjunction with other ground-motion parameters as a measure of frequency content.

Some predictive equations for PGV have been published, but far fewer exist than for other parameters such as peak ground acceleration (PGA) or spectral ordinates. Published PGV predictive equations for Japan show general agreement, while equations for Europe and the Middle East present large differences amongst the median values. Despite the abundance of strong-motion records from western North America there are few PGV predictive equations for this region. Equations for stable continental regions applicable to a wide range of distances and magnitudes only include those developed in eastern North America (ENA).

Because of the shortage of predictive equations, a need exists to develop a method for estimating PGV from the 5% damped response spectra derived from published ground motion equations or from design spectra. In order to develop such a method, a large strong-motion dataset was used to investigate four possible procedures. The dataset was supplemented by tests using empirical equations and from stochastic simulations for ENA and coastal California regions. The methods investigated comprised scaling of spectral ordinates at 0.5 second period, scaling of peak pseudo spectral velocity and use of random vibration theory. A fourth method in current common practice scales PGV from the 1 second spectral ordinate; however, the scale factor was found to vary strongly with earthquake magnitude, and the method is not recommended.

### CONSTRUCTION OF UNIFORM HAZARD SPECTRA USING MONTE CARLO SIMULATION – ID 247

*T. Sen, KBR, UK*

Earthquakes cause damage to engineering structures and often results in loss of lives. Forecasting an exact time of an earthquake can at best reduce casualties, which at present seems to be an impossible task. Therefore, structures need to be designed to withstand the impact of an earthquake and prevent collapse as it is buildings that kill people and not earthquakes.

Large magnitude earthquakes are low probability but high risk events. Design all structures for this rare event may prove to be expensive i.e. uneconomic as many of these structures may not, in its lifetime, experience this event. Thus a balance between safety and cost must be sought i.e. a decision making. Unfortunately, there are many areas of uncertainties in determining loads due to future earthquakes and this makes decision making difficult.

Seismic hazard analysis (evaluating design parameters of earthquake ground motion at site) provides useful guidelines for informed decision making.

Probabilistic treatment of seismic hazard analysis ('sha'), first introduced by Cornell (1968) in a landmark paper, is now widely accepted. It provides a sound theoretical basis for representing various seismic natural variability and allows treatment of uncertainties arising from incomplete knowledge.Typically, earthquakes can occur at any location along the fault line. This makes the distance from the source to the site a randomly variable quantity. The magnitude

of the earthquake also is random in nature together with expected levels of ground shaking. The concept of uniform hazard spectra (uhs) follows directly.

This paper outlines the basic concepts of probabilistic modeling and the underlying assumptions. This is followed up with a worked example illustrating the various steps using Monte Carlo simulation. Comparisons of 'uhs' are presented using different attenuation relationships. Related topics of de-aggregation and logic-tree formulation are discussed in sufficient detail.

### SELECTION OF TIME SERIES FOR ANALYSES OF RESPONSE OF BUILDINGS – ID 248

*J. Watson-Lamprey, University of California, Berkely, United States*
*N. Abrahamson, PG&E, United States*

To obtain design time series, it is common practice to select empirical recordings of ground motion and modify then modify them by scaling or by making them spectrum compatible. The computed non-linear response of a structure can vary greatly depending on the recordings selected. Watson-Lamprey and Abrahamson (2005) proposed a procedure to select time series for use in non-linear slope-stability analyses with the objective of finding time series that lead average response of the non-linear system. We extend this procedure to develop an objective method for selecting time series for use in non-linear structural response analyses. Non-linear response spectra are used as a proxy for the non-linear response of structures. Using a suite of recorded and scaled ground motions as inputs, a regression analysis is performed to develop a model for the non-linear oscillator displacement based on the properties of the record and the oscillator. The spectral shape beyond the fundamental period of the oscillator has a large effect on the response as does the uniform duration of the input ground motion. Using the PEER NGA strong motion database, a model for uniform duration is derived based on typical design scenario parameters (magnitude, distance, VS30, epsilon). Time series for use in non-linear structural analysis are then scaled to the spectral acceleration at the fundamental period. Records with uniform duration and spectral shape close to the median value for the design event are selected as records that

### CRITICAL REVIEW OF THE CURRENT APPROACH FOR DETERMINATION OF THE SEISMIC ACTION FOR SERBIA – ID 254

*M. Manic, Institute of Earthquake Engineering, Macedonia*
*B. Bulajic, The Highway Institute, Yugoslavia*

This paper presents the critical review of the current approach for definition of the earthquake action for seismic design of structures in Serbia. It has been pointed to the inadequacy of the current seismological maps for the territory of Serbia, which are based on the values of macroseismic intensity, as well as to the uncertainty of the design ground acceleration values that result from such maps. Based on the results from our earlier investigations for some particular locations in Serbia, it has been shown that depending on the amplification effects of the local soils these acceleration values could be significantly overestimated or underestimated. Necessity of the production of future seismic hazard maps based on the ground acceleration is reviewed from the aspect of choosing appropriate attenuation curves for the region of northwestern Balkan, as well as from the aspect of defining the spectral types according to Eurocode 8.

### SEISMIC HAZARD AROUND ZAGROS MOUNTAINS A CASE STUDY ON ZHAVEH RESERVOIR DAM SITE AND WATER TUNNEL – ID 483

*K. Hadavi, Moshanir Eng. co., Iran (Islamic Republic Of)*
*A. Farazmand, Moshanir Eng. co., Iran (Islamic Republic Of)*
*H. Bagheri, Moshanir, Iran (Islamic Republic Of)*

The NW-SE trending Zagros fold and thrust belt extend for about 1800 Km from SW of Iran to NE of Turkey. Zhaveh reservoir dam site which is located on the border of High Zagros and Maragheh – Sirdjan seismotectonic provinces, mostly affected by the earthquakes of Zagros. Moreover, a 60Km water tunnel will transfer the future reserved water to the south, nearby Kermanshah city. An area with the radius of 150 km around dam site has been considered as the effective zone. In addition to Maragheh – Sirdjan, High Zagros seismotectonic province, is also surrounding the dam site. The line sources within this area were identified by all existed data. Maximum credible earthquake in the above-mentioned area is about 7.4. Avihang fault is capable of producing an earthquake with a magnitude of 6.9, has the highest impact on the site, and is capable of producing the maximum ground motion. Earthquakes with the magnitudes of 6.3, 6.7 and 7.2 were established for return periods of 150, 500 and 2000 years, respectively. Computation of the return periods of the strong ground motion was made through the use of Seisrisk III program. Three attenuation models (Campbell & Bozorgnia 2003, Ambraseys & Douglas 2003 and Zare & Bard 1999) were applied where maximum accelerations as DBL, MDL and MPL, were to be calculated for selected exceedance probabilities for the service life respectively. Seismic design level parameters for the dam site (beginning of the tunnel) were obtained as follows: DBL : 0.21g(h), 0.14g(v), MDL : 0.30g(h), 0.15g(v) , MPL: 0.45g(h), 0.24g(v)and MCL : 0.67g(h), 0.42g(v). Seismic design level parameters were also calculated along the tunnel with adequate distance of points. Rupture hazard and maximum displacement for crossed faults with the tunnel line were also investigated along the tunnel.

### EARTHQUAKE HAZARD INVESTIGATION FOR YAZD POWER PLANT BY A VIEW ON SEISMIC HAZARD MICRO ZONING – ID 562

*A. Farazmand, moshanir Eng, co., Iran (Islamic Republic Of)*
*H. Bagheri, Moshanir Eng. co., Iran (Islamic Republic Of)*

Due to the fact that Iran lays on one of the most active seismic belts in the world, great attention must be paid to seismicity hazard analysis, specially for important projects such as power plants. Numerous seismic hazard studies on Yazd region shows that inspite of relative calm in the seismic activity of this region, it still is threatened by major seismic activity. In the present study, an earthquake hazard micro-zoning, has been done for Yazd city for the purpose of allocating the regional power plant. In the initial stages, aerial and satellite photographs were studied in order to detect faults in the region, moreover, a catalogue of earthquake were complied. As a result, high potential areas were detected. The following methods were used in the Seismic hazard micro-zoning 1-Geotechnical surveys by drilling a number of boreholes. 2-Geophysical surveys composing of: a) Micro tremor study for analyzing amplification facture and natural frequencies. b) Seismic downhole survey in order to obtain wave velocities. As a result of this study, number of maps was obtained. There were: - Iso-amplification and sio-frequency maps - Iso-seismic wave velocity at various depths. Using these results distribution of earthquake acceleration across the town was obtained for various return periods. Earthquake hazard was thus evaluated for the region using the outcome of the studies preceding. Acceleration spectral analysis for the power plant site was carried out using MCL, MDL, DBL, ...az for , 475 years R.P. 0.20g (H), 0.11g (V) and 2475 years R.P. 0.33g (H), 0.18g (V) .

### SEISMOTECTONIC AND SEISMIC HAZARD ANALYSIS OF WEST KERMAN POWER PLANT SITE – ID 573

*A. Farazmand, Moshanir Eng. co., Iran (Islamic Republic Of)*
*K. Hadavi, Moshanir Eng. co., Iran (Islamic Republic Of)*
*H. Bagheri, Moshanir Eng. co., Iran (Islamic Republic Of)*

The site area for Kerman Power Plant is located about 25 km from the City of Kerman. The concerned area is among the most earthquake prone areas of the Iranian Plateau. Kerman Power Plant which is located on the Rafsanjan-Kashmar seismotectonic province, is mostly affected by the earthquakes of north and east of Kerman. An area with the radius of 150 km around power

plant site has been considered as the effective zone. Studying the Landsat7 ETM 2000 satellite imageries, available maps and other seismic data, has identified the main faults as Baghin, Darivan and Bazargan, situated at 3, 30 and 38 km respectively from the site. The line sources within this area were identified by all existed data. Maximum credible earthquake in the above-mentioned area is about 7.4. Baghin fault is capable of producing an earthquake with a magnitude of 7.2, has the highest impact on the site, and is capable of producing the maximum ground motion about 0.70g. Earthquakes with the magnitudes of 6.3, 6.8 and 7.4 were established for return periods of 50, 150 and 500 years, respectively. Computation of the return periods of the strong ground motion was made through the use of many softwares. Three attenuation models (Campbell & Bozorgnia, Ambraseys & Douglas and Zare & Bard) were applied where maximum accelerations as DBL, MDL and MPL, for selected exceedance probabilities of project life time.Seismic design level parameters for site were obtained as follows: For 50 years R.P. 0.12g (H), 0.07g (V), 475 years R.P. 0.23g (H), 0.12g (V), 2475 years R.P. 0.36g (H), 0.18g (V) and 10000 years R.P. 0.46g (H), 0.24g (V) Also, using the analysis of the return period of spectra ordinates, Equal Probable Response Spectra for different seismic design levels have been obtained.

## AN ANALYTICAL STUDY ON THE SEISMIC CHARACTERISTICS OF THE GROUND AND STRUCTURE – ID 756

*R. Nasser, Tokyo Metropolitan University, Japan*

In order to implement the proper seismic design of structures in Damascus, the seismic behavior of soil and structure was examined numerically, and the seismic characteristics of them both were determined. The study is carried out through two major steps; first, examining the seismic response of ground due to strong and weak earthquake motions; second, examining the soil-structure interaction due to the same motions. All seismic characteristics of both ground and structure will be determined from this analysis such as shear forces, displacements, bending moments, stresses ...etc. strong nonlinear properties were displayed, which proved the Equivalent Static Method used in Syria insufficient.

## IDENTIFICATION OF EFFICIENT GROUPS OF DESIGN EARTHQUAKE INPUTS – ID 961

*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*
*D. Malavolta, DISTART - Department of Civil Engineering, Italy*

In recent years, Performance Based Seismic Design (PBSD) has played a central role for research works in the field of seismic engineering. The core idea of the PBSD is the probabilistic assessment of the structural performances due to seismic action [Bertero and Bertero 2002, Moehle and Deierlein 2004, Zhang et al. 2004]. Within this framework a central role is played by the so called "Probabilistic Seismic Demand Hazard Analysis (PSDHA) [Zhang et al. 2004]. As pointed out in recent scientific contributions [Giovenale et al. 2004] the main shortcoming which prevent the effective application of such a approach currently lies in the large dispersion (i.e. large variability) of the structural response (as evaluated through properly chosen Damage Measure DM or Estimated Damage Parameters EDP) obtained from non-linear dynamic analysis which uses as input selected earthquake acceleration time histories. A number, of scientific work have recently focused upon the identification of the "optimal" procedure for the identification of representative (i.e. characterized by a given probability of occurrence) groups of earthquake inputs which lead to a reduced dispersion of the structural response ("efficient" groups of earthquake). This paper, referring to a general procedure for the identification of representative groups of earthquake inputs proposed by the authors: (a) compares the results which can be obtained following different rules for the application of the methodology proposed, (b) identifies a practical proposal for the effective application of the methodology based upon the use of a vector-valued IM composed of Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV), (c) proposes the use of "representative" EPI groups characterised by a (1) a vectorial IM composed of PGA and PGV and (2) a specific relative ratio of near-field records to far-field records.

## PROBABILISTIC SEISMIC HAZARD MAPS FOR ROMANIA AND BULGARIA AS A BASIS FOR A NEW BUILDING CODE – ID 1019

*L. A. Ardeleanu, National Institute for Earth Physics, Romania*
*S. Simenova, Geophysical Institute of Bulgarian Acad of Science, Bulgaria*
*D. Solakov, Geophysical Institute of Bulgarian Acad of Science, Bulgaria*
*G. Leydecker, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*H. Busche, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*T. Schmitt, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*D. Kaiser, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*K. P. Bonjer, Geophysical Institute of University of Karlsruhe, Germany*

Seismic hazard maps as part of a new building code based on EUROCODE 8 (EC8) require a unique hazard parameter such as macroseismic intensity. EC 8 recommends two hazard maps, one for a probability of exceedance of 10% in 10 years (recurrence period of 95 years) and one for 10% in 50 years (recurrence period of 475 years). We computed the seismic hazard with EQ-RISK based on the probabilistic approach developed by Cornell. We used the earthquake catalogue for Central and Southeastern Europe (342 BC - 1990 AD), for Bulgaria (1981 - 1990) and for Greece (550BC - 2004). The most consuming work was to establish a unified catalogue.

Seismic source zones inside an area of about 200 km around Romania and Bulgaria were defined and are based on seismicity, neotectonics and geological development. For each seismic source a maximum possible earthquake as well as a seismogenic depth has been estimated.

To cope with the irregular isoseismals of the Vrancea intermediate depth earthquakes a factor omega; has been included to the attenuation law:

Isite = Iepic -3log(r/h) -1.3 alpha*omega*(r-h)

r = hypoc. dist.; h = depth; alpha = absorption coeff. [1/km]

Using detailed macroseismic maps of three intermediate depth earthquakes omega has been calculated for each observation with alpha fixed. The contribution of the Vrancea intermediate depth zone to each grid point was computed with the corresponding representative omega of this point. A seismogenic depth of 120 km has been assumed.

The final seismic hazard is the combination of both contributions, of zones with crustal earthquakes and of the Vrancea intermediate depth zone. For Romania the most contributing hazard is related to the Vrancea intermediate depth zone. In Bulgaria the region with the strongest earthquakes and highest hazard is the Kresna region south of Sofia.

## SEISMO-ENGINEERING PARAM. FOR INTERIM STORAGES OF SPENT NUCLEAR FUEL AT GERMAN NUCLEAR POWER PLANTS – ID 1026

*G. Leydecker, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*T. Schmitt, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*H. Busche, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*T. Schaefer, Federal Office for Radiation Protection, Germany*

The Federal Institute for Geosciences and Natural Resources was charged by the Federal Office for Radiation Protection to author expert reports about seismo-engineering parameters for the sites of the planned interim storages of spent nuclear fuel at 13 nuclear power plants (NPP) in Germany. We compared our own independent site specific expertises with these presented by the owners of the NPP for the licensing procedure and came to a finalization.

The basis for our work was the German standard "Design of Nuclear Power Plants against Seismic Events" of the German Nuclear Safety Standards Commission as well as newer developments in sci-

ence and technology and the earthquake catalogue for Germany since the year 800. For each of the 13 sites, site dependent analyses were done including seismic hazard assessment and evaluation of design spectra. The intensity of the site corresponding design earthquake was worked out on a deterministic way and - unless the earthquake data satisfied a reliable interpretation - on a probabilistic way. The design earthquake was estimated for a probability of exceedance of 10E-5/year, also with respect to geological development and neotectonics in the surroundings.

For sites with a design earthquake greater than intensity VII MSK, we made an own evaluation of worldwide strong-motion records. These records have to comply with the strength of the design earthquake and they must be registered in suitable hypocenter distances and at comparable soil conditions. Using more than 50 records for each site, the response spectra were computed and the median has been taken as the site specific response spectrum. For all other sites we used published response spectra which had to fulfil the estimated strength of the design earthquake and the site specific soil conditions.

In addition to the design earthquake and the response spectrum a strong-motion duration was estimated.

## CONDITIONAL SIMULATION OF SPATIOTEMPORAL EARTHQUAKE RANDOM FIELD – ID 1093

*R. Jankowski, Gdansk University of Technology, Poland*

Simulation of space-time variation of earthquake field by the deterministic approach, which traces the wave propagation through the soil, is very complex. Therefore in earthquake engineering, the stochastic approach has been proved to be very useful and successfully applied in practice. The incorporation of the seismic wave propagation effect is especially important when large structures with spatially extended foundations, such as long bridges, dams, life-line systems and large buildings, are analyzed (see [1]). This is due to the fact that their dynamic response can be significantly altered due to the spatial variations of ground motion causing different seismic input acting on different supports of the structure. Detailed analysis of the response of large structures requires the generation of acceleration records for different locations of supports based on the specified record. This can be achieved by applying the conditional stochastic modelling approach. The aim of the present paper is to propose a method of conditional stochastic simulation of ground motions using the spatiotemporal correlation function. Defining the correlation function of earthquake field in space and time simultaneously allows us to model the seismic wave propagation effect more realistically. Moreover, it overcomes the disadvantages of existing methods concerning the issue of identifying the time correlation of the field (see [1] for example). The method proposed has been used to generate unknown acceleration time histories at various structural supports based on the specified earthquake record at one location. The results of the study show that the method gives relatively low simulation errors. Thus, it can be used for the practical purposes in order to generate the input ground motion records for structural dynamic analysis of large structures under earthquake excitation.

[1] Jankowski, R., Wilde, K.: A simple method of conditional random field simulation of ground motions for long structures. Engineering Structures 22 (2000) 552-561

## RESPONSE SPECTRA OF THE STRONG MOTIONS IN IRAN: A CASE STUDY IN ALBORZ REGION – ID 1145

*M. Zare, IIEES, Iran (Islamic Republic Of)*
*H. Ghassemi, IIEES, Iran (Islamic Republic Of)*

The reponse spectra of the strong motions in Iran are studied in order to determine the spectral ordinates for different seismotectonic provinces of Iran as well as site classes. This may provide a basis for developing the spectral attenuation laws as well as the design spectra. The pilot study region is selected in the Alborz Belt - in northern Iran - in order to determine the design spectra. A collection of about 500 strong motion degital records are selected for present study. The records are selected from the database of the Iranian National Strong Motion Network out of about 6000 three-component data obtained between 1975 and the end of 2005. The records are selected in a manner that the strong motions represent the site classes and the seismotectonic conditions in the Alborz mountains. The selected records comprises the great earthquakes of Manjil of 20 June 1990, Mw7.3 and Firouzabad, Kojour of 28 May 2004, Mw6.2. There is still a lack of near-source strong motion record for the region of Tehran, the capital of Iran with a population of 13 million. However the records of a magnitude Mw3.7 earthquake in 9 March 2002 originated from the reactivation of north Tehran fault was among the selected records. The major results of this study might be classified as: 1) the response spectra in the Alborz belt are representative for the greatest response spectral amlification levels in the low periods (0.1 to; 0.2 seconds). 2) The spectra for four sites classes shows the higher amplifications in the longer periods (around 1 second) for the soft soil sites.

## SYSTEM APPROACH TO SEISMIC CONDITIONS ESTIMATION AND DESIGN SEISMIC LOADINGS EVALUATION – ID 1176

*A. Savich, Geodynamic Research Center, Russian Federation*
*V. Besstrashnov, Geodynamic Research Center, Russian Federation*
*A. Bugaevskiy, Geodynamic Research Center, Russian Federation*
*A. Suvilova, Geodynamic Research Center, Russian Federation*
*V. Stepanov, Geodynamic Research Center, Russian Federation*
*N. Burdina, Geodynamic Research Center, Russian Federation*
*A. Godzikovskaya, Geodynamic Research Center, Russian Federation*

Approximately for 100 large power objects of Russia, an estimation of their seismic and geodynamic conditions accepted at designing essentially can differ from recent estimations based on new normative map OSR-97. This difference, as a rule, is expressed in design seismicity increasing at 1-2 points, and for some objects - at 3 points in MSK-64 scale. It demands revision of design seismic parameters and, in some cases, new calculations of construction seismic resistance. We develop a technique of system approach to seismic conditions estimation, allowing optimizing scope and methods of necessary detailed researches for normative characteristics refinement. It has enabled obtaining the required information in short enough terms, both at designing new projects, and at seismic conditions refining for already maintained constructions. Basis of this technique is study in system interrelation of the following elements: –·allocation of main seismogenic zones based on combined analysis of all available seismological, geological and geophysical data using both probabilistic (at presence of sufficient earthquake statistics), and deterministic approaches; –·maximum full consideration of strong earthquake data for studying territory for probably longer period of time, comparable to strong earthquakes recurrence period. For this purpose, instrumental and historical earthquake data and paleoseismological researches are used; –·careful analysis of instrumental seismological data and earthquake catalogues "cleaning" (discrimination of industrial explosions creating false source zones and essentially distorting real seismicity pattern); –·creation and regular updating of databases on parameters of hazardous geodynamic processes; –·determination of seismic potential of revealed seismogenic zones in view of their geometry, the most probable source mechanisms and tectonic evolution dynamics; –·application of initial data complex for preliminary seismic loading evaluation: positions and characteristics of main seismogenic zones, seismic wave attenuation characteristics, interior structure at the source-site trace, and etc.; –·determination of refined seismic loadings in view of site-specific features.

## MODIFICATION OF THE EUROCODE 8 DAMPING REDUCTION FACTORS FOR DISPLACEMENT SPECTRA – ID 1203

*R. Mendis, Imperial College, UK*
*J. Bommer, Imperial College, UK*

Displacement response spectra for damping ratios significantly higher than the nominal 5% of critical are required for the design of base-isolated structures and structures with supplemen-

tary damping devices, as well as for performance-based design approaches that use equivalent linearization. The spectra for higher damping values are generally obtained by applying scaling factors to the 5%-damped ordinates and are normally defined as functions of the damping level and sometimes also the response period. In the case of Eurocode 8 (CEN, 2003), the damping reduction factor that is provided is currently applied to two types of spectra. The Type 1 spectrum is for regions of high seismicity and hazard and Type 2 is for regions of NW Europe where magnitudes are unlikely to exceed Ms 5.5.

An extensive literature review of global design codes reveals great variation in the scaling factors presented. This is interpreted as being due to the different characteristics of the ground motions used to derive them, since the scaling of the 5%-damped ordinates for higher damping levels displays a marked dependence on strong-motion duration. Duration-dependent scaling factors for higher damping levels are derived using an extensive strong-motion dataset of approximately 1,500 strong-motion records. These new scaling factors are compared to the current damping reduction factors of Eurocode 8 (EC8).

There is good agreement between the duration-dependent scaling factors and the EC8 scaling factors at large values of duration, which correspond to the Type 1 spectrum. However, the results show that for shorter durations, which correspond to the Type 2 spectrum, the current EC8 factors are not appropriate. New scaling factors are proposed for the Type 2 spectrum, which account for the shorter durations of ground motions in the lower seismicity areas of Europe.

## SELECTION OF SPECTRUM-COMPATIBLE REAL ACCELEROGRAMS FOR SEISMIC RESPONSE ANALYSES OF SOIL DEPOSITS – ID 1240

*A. Dall'Ara, Politecnico di Torino, Italy*
*C. Lai, EUCENTRE, Italy*
*C. Strobbia, EUCENTRE, Italy*

Local site effects and nonlinear dynamic analyses of structures are examples of problems in earthquake engineering that require the seismic input to be specified in terms of accelerograms. According to Eurocode 8 the accelerograms may be either artificial (i.e. generated using stochastic algorithms), recorded in real earthquakes, or simulated (i.e. generated by modeling the earthquake mechanics). Recorded accelerograms are obviously to be preferred as they possess a realistic frequency content and a proper phase correlation among components. An important feature that accelerograms used for dynamic analyses should possess is the so-called spectral compatibility which relates to the fact that the misfit between the average response spectrum computed from the accelerograms and a target spectrum (e.g. obtained from a probabilistic hazard study) should not exceed a certain tolerance within a specified range of periods. Spectral-compatibility is not a simple requirement to be enforced if using real accelerograms, however it is an important feature in order to avoid the use of records that are incompatible with the results of a seismic hazard study. This paper illustrates a procedure for the selection of spectrum-compatible recorded accelerograms at sites located in Northern Tuscany (Italy). The study was conducted by first performing a probabilistic seismic hazard assessment at the regional scale. Uniform hazard response spectra were computed for different return periods followed by a process of deaggregation to identify the earthquake scenarios controlling the hazard. The magnitude-distance pairs obtained from deaggregation have then been used to select seven natural accelerograms that are compatible with the calculated probabilistic response spectra. The choice of the accelerograms has been facilitated by an automatic procedure that allowed to analyze 109 combinations of 60 natural accelerograms. The selected records have finally been used to assess the variability of seismic response at a site.

## EXPLOITATION OF TUNISIAN SEISMICITY DATA FOR SEISMIC HAZARD EVALUATION OF CIVIL ENGINEERING FRAMEWORK – ID 1286

*B. Chelli, National Institute of Scientific and Technical Res, Tunisia*

The (STEG) has developed a seismicity study of Tunisia related to important energy production setting.

This study is based on three axes:

-Historical seismicity; -Instrumental seismicity in the last century; -Microseimicity related with electric central seismicity.

The historical seismicity data was based on previous manuscripts, reports and catalogues. The compilation of these data has ameliorated the Catalogues of N. N. Ambraseys (1962) and J.P. Rothé (1967).

However, this study was insufficiently to allow a precise location of earthquakes. In fact, the exploitation of some "iso-seistes" was used to elaborate a law for the calculation of intensity after the focal distance.

The instrumental seimicity study in the last century has permitted to identify the major outlines of the seimic active zones in Tunisia and surroundings areas. Using microseimcity we were able to complete the historical and instrumental studies essentially near the active structures in northern Tunisia.

Finally, the exploitation of the elaborated data base concerning the seismicity of Tunisia and the surroundings area allowed the evaluation of the seismic risk related to important buildings in the electric production sector. We use in this paper an appropriated method to develop this problematic.

## TO THE PROBLEM OF IDENTIFYING SEISMIC LOADS ON BUILDINGS IN THE CITY OF ALMATY – ID 1336

*M. Ashimbaev, KazNIISSA, Kazakhstan*
*V. Lapin, KazNIISSA, Kazakhstan*
*T. Zhunusov, KazNIISSA, Kazakhstan*

Thus the region is subject to severe seismic events with magnitude 8 having 10-40 kilometer depth of focus. All that imposes a high responsibility onto experts dealing with calculations and designing of buildings and constructions lying within the territory of the city. It is quite appropriate to note here that a magnitude is an objective physical feature of an earthquak's focus what necessitates it being taken into account for accurate determination of seismic loading on buildings and constructions. Such methods were developed in the late 80s early 90s and were named as "M" methods. (I.L. Korchinsky, T.Zh. Zhunusov). Within the mentioned above theory a magnitude value of an earthquake not its seismic grade was assumed as the major feature of earthquake. The summary of the theory is stated in "Determination of siesmic loads on a building regarding parameters of an earthquake's focus." ( I.L. Korchinsky, T.Zh. Zhunusov, V.A. Lapin).

Within "M" theory spectral curves B and amplitude characteristics Kc (seismicity ratios) were made up. These parameters are adduced in chart I, where r is hypocentral distance, R is a radius of an epicentral zone depending on a magnitude of an earthquake.

## THE IMPACT OF SOIL CONDITIONS ON THE DESIGNED SEISMIC CHARACTERISTICS – ID 1337

*M. Ashimbaev, KazNIISSA, Kazakhstan*
*V. Lapin, KazNIISSA, Kazakhstan*

The influence of soil conditions on seismic effect in Almaty and adjacent regions was discovered based on the instrumental and macro-seismic intensity evaluation of seismic forces at the explosions. Our institute registered vibrations of buildings and soils. Almaty is divided into 3 major sites. On the first site which is located on the mountain footing zone and according to its seismic properties characterized by soil of first category (Southern part of the city), soil amplification with respect to rocks was not reported.

In the Central site which is characterized by soil of category II the site amplification was recorded as I-II relative to that on rock. The Northern part of the city is located on soils of category III. Here, the site amplification effect was reported up to II comparing with that on the rock and +0.5 comparing with the Central site. Analysis of instrumental data included not only determination the soil amplification effect but also the comparison of gain-frequency characteristics of soils by construction Fourie spectra. In the

Southern part the predominant frequency is approximately 2 Hz, in the Central 1.4 Hz and in the Northern 0.5 Hz. From other results the strong influence of relief on the seismic effect of the explosions was observed. On the peaks and on the slopes of the hills the intensity rises from 2 to 4 times comparing with the sites located on the bottom of canyons, valleys etc. For example, if on the bottom of canyon the amplitude was registered within 1.8-2.7 mm, then on the slopes 4-7.5 mm.

### SEISMIC DESIGN OF GUSSET PLATES OF SCBF IN I BEAM TO BUILT UP BOX COLUMN CONNECTIONS – ID 1409

*S. R. Mirghaderi, Tehran University, Iran (Islamic Republic Of)*
*A. Alipour, Tehran University, Iran (Islamic Republic Of)*

R.Mirghaderi; Assistant Prof.of university of Tehran A.Alipour; Msc, Earthquake Engineering graduate student, University of Tehran

Seismic Design of Gusset plates of SCBF in I Beam to Built up Box Column Connections Special concentric braced frames are recognized as a very efficient lateral load resisting system for seismic forces. The axial forces, tension and compression, in bracing members are assumed to perform as displacement controlled components, in a ductile manner without considerable strength degradation while other connecting parts, such as force-controlled components ,more or less act in elastic range. In an appropriate seismic design of SCBF, providing a proper load path which transfers the ultimate expected forces induced in bracings to beam-column connections is the main concern. In common practice, design of connections between bracing gussets and I beam/H column has four different approaches for load transfer which are generally based upon slightly different assumptions but in all of them it is assumed that bracing forces are transferred straightly from gusset plate to beam/column webs through a planar manner. Common steel construction in Iranian practice is composed of built up box sections for columns with I beams either passing through two side of column or connecting to column face. The connection of bracings gusset plates are no longer follow the planar transfer of bracing forces to beam/column joints which is the basic assumption of above mentioned common design practice. In this paper the load transfer mechanism and proper detailing of bracing gussets to I beam/built up box column are examined through an elaborated finite element analysis and tried to establish a convenient through gusset late for these type of connections.

### UNCERTAINTIES AND APPARENT INCONSISTENCIES IN PSHA STUDIES: EXAMPLES IN FRANCE – ID 1434

*Gepp And Afps Working Groups, France*

Over the past five years, several PSHA studies have been performed on the French territory by different teams from different institutes and within different frameworks. The results vary from one study to another, someimes only slightly, sometimes very largely (up to one order of magnitude in terms of pga values on rock for "standard" return periods around 500 years). The aim of the presentation is to discuss the origins of such a variability, and to outline the key issues. A PSHA study is based on data (earthquake catalogs, historical and instrumental periods; ground motion data for atenuation relationships), on models (magnitude distribution, recurrence, accounting for epistemic and aleatory uncertainties, distribution of residuals for attenuatioon relationships,etc.), and on assumptions (source zones, maximum magnitudes, importing attenuation relationships, etc.). For the various PSHA studies considered here, the catalog is approximately similar; differences in magnitude and depth estimates for historical events may however result in significant differences (30 to 40%); the seismotectonic zonations are different, but do not basically change the order of magnitude of median pga values – though it does affect the spatial distribution. Maximum magnitudes play a significant role only at large return periods and for spectral values at low and intermediate frequency, while minimum magnitude is important for small return periods. However, the largest differences prove to be associated with the attenuation relationship. Factors of up to 3-5 arise from the choice of attenuation relationship, especially when relations derived from small to moderate events are used. Consequences may be either overestimation of hazard in low seismicity areas, or understimation of hazard in moderate to high seismicity areas. Factors of at least 2 are associated with the accounting or not of the standard deviation on attenuation relationship. Finally factors around 1.5 are associated with magnitude conversions.

### THE EFFECT OF BACKGROUND RECORD ON RESPONSE OF STRUCTURES SUBJECTED TO NEAR-FAULT GROUND MOTIONS – ID 1512

*M. A. Ghannad, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. Jahankhah, Sharif University of Technology, Iran (Islamic Republic Of)*
*S. F. Ghahari, Sharif University of Technology, Iran (Islamic Republic Of)*

Ground motions records close to ruptured fault possess special characteristics not seen in other ground motions. Directivity, fling step, notable vertical components and a band of grater (high) frequency content are remarkable ones of those characteristics. Influence of such parameters, on response of structures has been the title of several investigations in recent years. Among mentioned items, directivity pulses gained more attention and different pulse characterization methods are proposed to include directivity effect. But rarely the effect of pulse and background record have been considered simultaneously. However, it is shown here that the background record may also play an important role in specific situations. In this study, the effect of directivity pulses on the response of structures within a wide range of natural periods, in the presence of a controlled background has been investigated. For this purpose, the pulse characteristics are defined based on different proposed methods while a statistical approach is chosen for the background record.

### STUDYING THE ENERGY DISSIPATION IN EBFS SUBJECTED TO EARTHQUAKE BY USING NONLINEAR DYNAMIC ANALYSES – ID 1525

*M. Hosseini, IAU, Iran (Islamic Republic Of)*
*M. Esmaeili, IAU, Iran (Islamic Republic Of)*

Most of the existing seismic design codes suggest the use of a “response modification factor” in calculation of the equivalent earthquake load to account for the energy dissipation of the structure. This factor appears in the calculation of the building total seismic shear force rather than the lateral load distribution. This means, implicitly, that the plastic behavior or energy dissipation of the system is assumed by the code to be almost the same in its various stories. To find out how far the actual distribution of plastic hinges is from the code assumption some sets of steel buildings with eccentrically braced frames have been studied by nonlinear time history analyses (NLTHA). The buildings have up to 15 stories and up to 3 bays, and have been analyzed by several real accelerograms. The formation trend of the plastic hinges in various elements of steel frames and the distribution of plastic hinges over the structure, as well as the amount of energy dissipation is various stories have been studied. Numerical results show that the code assumption is far from reality in most cases. This means that the code suggested pattern for calculation of equivalent lateral loads is not realistic. On this basis, it has been tried to obtain a new lateral load pattern by using the results of the NLTHA. Then, the buildings have been redesigned by that average load pattern, and the NLTHA have been repeated. Good agreement is observed then between the actual load distribution and the average pattern used for the redesign, and the distribution of plastic hinges are more uniform. By calculating the ratio of the values given by the average load pattern, obtained by NLTHA to those given by the suggested pattern of the code a somehow new concept of “story-dependent response modification factor” have be defined.

## DEFINITION OF SIMULATED ACCELEROGRAMS CONSISTENT WITH THE ITALIAN NATIONAL SEISMIC CODE – ID 1730

*A. Masi, DiSGG, University of Basilicata, Italy*
*M. Dolce, DiSGG, University of Basilicata, Italy*
*M. Mucciarelli, DiSGG, University of Basilicata, Italy*
*M. Vona, DiSGG, University of Basilicata, Italy*

In most of the seismic codes the seismic motion may be represented also in terms of ground acceleration time histories. To this purpose artificial, simulated or recorded accelerograms can be used. Some rules shall be observed in the definition of the accelerograms, mainly relevant to their duration, number and coherence to the elastic response spectra given in the code. Artificial spectrum-compatible accelerograms can be generated using programs such as SIMQKE. Simulated accelerograms can be obtained through a physical simulation of source and travel path mechanisms. Finally, real accelerograms recorded during past seismic events can be used, also drawing them from the available strong-motion databanks. Criteria for selecting time histories that can be used by the practising engineering in seismic analysis and design are strongly needed. In this work some sets of acceleration time histories consistent with the current Italian seismic code, whose rules substantially coincide with EC8, are obtained. A computer program named BELFAGOR derived from an older code (Mucciarelli et al., 1997) based on the theoretical work by Sabetta and Pugliese (1996), will be used. Two conditions are fulfilled using BELFAGOR: 1) mimic real accelerograms for similar magnitude, distance and site conditions; 2) converge in frequency domain to a reference spectrum, and in particular to response spectra provided by seismic codes. 12 sets of time histories are generated, according to the 4 different seismic zones and the 3 different ground types considered in the Italian code. Each set include at least 7 accelerograms so that, when used in the non linear analyses, the average of the response quantities may be used in the safety verifications. The ability of BELFAGOR in providing suitable time histories, particularly when compared with SIMQKE, will be shown by carrying out non linear dynamic analyses on some RC frame models.

## SEISMIC RESPONSE OF CONCRETE LIQUID CONTAINING STRUCTURES – ID 1733

*R. Kianoush, Ryerson University, Canada*

There are currently few guidelines and standards available in North America for the design of liquid storage tanks. The ACI Committee 350 has recently published a new code and commentary for liquid containing structures. In a companion document, ACI 350.3/350.3R provides directions to the designer of liquid containing concrete structures for computing seismic forces that are to be applied to a particular structure.

There is a great deal of concern by the designers on the approach and the level of seismic forces that these structures are being designed. This is mainly due to the lack of understanding of the seismic behaviour of these structures. An extensive research project is currently underway at Ryerson University to resolve some of the issues of concern for design of these types of structures. As part of this ongoing research effort, in this paper, the dynamic response of rectangular tanks for liquid storage tanks is described.

In this paper, a brief overview of the basic concepts involved in the seismic analysis of liquid containing structures is presented. An outline of the basic theory that underlines the computation of earthquake-induced forces is discussed. The specific elastic deign response spectrum adopted by ACI 350 is discussed. The correlation between the classical equation and the lateral seismic force equations contained in ACI 350 is presented. The effect of the vertical and horizontal distribution of hydrodynamic forces on the wall of rectangular tanks is discussed.

In this study, the results of dynamic time history analysis for rectangular tanks are presented. The validity of the procedures adopted in Codes and Standards for determining the base shear for the impulsive and convective components is discussed.

## GROUND MOTION EVALUATION FOR TWO BRIDGES IN THE VENETIAN-FRIULI PLAIN (NE ITALY) – ID 1833

*P. Fadalti, Achille Fadalti Costruzioni S.p.A., Italy*
*A. Rebez, OGS, Italy*
*D. Slejko, OGS, Italy*
*M. Santulin, OGS, Italy*

The assessment of the expected ground motion is needed when new strategic facilities, as bridges, are designed. Two new bridges are planned in the Veneto-Friuli Plain (NE Italy) and, consequently, the expected seismic acceleration in the two locations have been computed. The two sites are both very interesting from the seismological point of view, as one is placed in the vicinity of potentially seismogenetic faults while the other is far from the deformation belt and was interested by several moderate historical earthquakes. For the two sites a standard PSHA evaluation using the logic tree approach has been performed. Moreover, the maximum possible and the design events for the two sites have been individuated. Finally, the uniform hazard response spectrum for the two sites has been computed together with synthetic accelerometric time histories compatible with the computed response spectrum.

## EXPERIMENTAL INVESTIGATION OF EARTHQUAKE RESISTANCE OF BUILDINGS WITH GIRTLESS FRAME AND STIFFENING DIAPHRAGMS – ID 2063

*I. Itskov, KazNIISSA, Kazakhstan*
*M. Ashimbayev, KazNIISSA, Kazakhstan*

Shake-test results of one of multistory buildings belonged to residence complex named "fantasy" which was designed & constructed by «Basis-A» corporation in Almaty are stated on given paper. The residence complex was built up on the site with 9-grade seismic intensity according to seismic properties the category of soil is-I. The tested object represented by a building compartment separated from adjacent compartments by seismic belts. The building compartment was designed as a structure with 10 overground stories, a basement floor and a technical room designed over the 10th floor. By the testing moment only the basement floor and 9 overground floors were completed. Dynamic loads applied onto the tested object were induced by means of inertia type shaker apparatus B-3 fastened rigidly to the 9th floor. During performed vibration testing the following was fulfilled: registration of vibrations and data preliminary processing, visual examination of constructions, both photo and video recording as well. During tests seismic detectors and tensometric crampons were used for measuring any concrete deformation within stiffening diaphragms. Complex analysis of experimental data allows to think that the tested building compartment has high capacity of resistance to seismic effects. According to testing results the recommendations on improvement of constructive solutions of bearing and non-bearing elements of the building with girtless frames and stiffening diaphragms.

## DYNAMIC TESTS OF A DWELLING HOUSE'S FRAGMENT WITH BEARING WALLS FROM GAS-BLOCKS – ID 2064

*J. Omarov, KazNIISSA, Kazakhstan*
*I. Itskov, KazNIISSA, Kazakhstan*

Dynamic forced vibration tests have been performed on a test model representing one-story dwelling house with mansard. The tested fragment was designed and constructed with axial sizes in plan 6x6 m and the height of 3 m. The construction weight of mansard was compensated by experimental equipment and dead load weight anchored to the floor slab. Forced vibrations have been generated byB-1 (testing stages one and two) and B-2 (testing stage three) vibrators installed on the roof of the constructed model. The first stage damages were minor, corresponding to damage

degree 1 according to MSK-64 scale, and were represented by fine cracks in gas-blocks accompanied by small opening in some horizontal and vertical joints between gas-blocks. The second stage damages to load bearing walls were rather serious represented by cracks in horizontal and vertical joints of the gas-blocks brickwork with permanent openings of up to 1...2 mm, diagonal cracks in piers, and concrete chopping off in some blocks. Inertial forces generated during the third stage of testing were quite comparable to the intensity of a real 9-grade seismic event. Walls of the test fragment (especially narrow piers) were heavily damaged (3-4 degree according to MSK-64) causing the reduction of horizontal stiffness of the fragment for approximately 20 times relative to the initial one. However, the tested fragment retained totally stable and did not collapse. The results of performed tests, including the analyses of available technical and economic indexes, proved that construction of few-story-buildings with load bearing walls of gas-blocks is feasible and should be rather perspective trend for seismic resistant construction in towns and in the country.

### OPTIMISATION OF PERFORATED CLAY UNITS IN CENTRAL EUROPEAN SEISMIC AREAS – ID 2068

*U. Meyer, Arge Mauerziegel e. V., Germany*
*M. Roßbach, Institut für Ziegelforschung, Germany*
*D. Schermer, Technische Universität, Germany*

Unreinforced clay unit masonry has proved to be an appropriate building material in low and moderate seismicity regions in Central Europe in the last centuries. Increased requirements resulting from the load codes were the starting point of investigations into the loadbearing behaviour of masonry walls under in plane shear loads. One among many other aspects is the optimisation of the product properties of vertically perforated clay units in shear walls. The optimisation process, carried out within the EU-sponsored research project ESECMaSE, comprised of an optimisation of the material composition as well as an optimisation of the perforation pattern. Prototype units were produced and tested. The assumed relevant material properties were significantly improved, but for the first optimisation step this didn't result in an improved resistance of the shear walls. Further optimisation is necessary and has already been started.

## CS2: Historical Investigations of Earthquake Effects, Damage and Vulnerability
Level-1

### SEISMIC VULNERABILITY OF SWISS HERITAGE BUILDINGS – ID 1994

*M. Devaux, Applied computing and mechanics laboratory, Switzerland*
*P. Lestuzzi, Applied computing and mechanics laboratory, Switzerland*

Switzerland faces a serious seismic hazard. Since the beginning of the first millennium, many strong earthquakes have struck this country. In 1356 for instance, the city of Basle experienced the most violent earthquake ever reported in Central Europe. Every earthquake has resulted in severe damage to the heritage buildings. For instance, the upper part of the steeple of the church in Visp (southern Switzerland) and the vaults of a smaller edifice in the surroundings (Visperterminen) collapsed due to the seismic event of 1855. The seismic safety of common buildings is well defined today in Switzerland through modern building codes; however, this is not the case of cultural heritage buildings, whose seismic vulnerability has been only partially addressed. In order to fill this knowledge gap, a national research program was initiated, whose main purpose has been to develop a methodology that allows us to assess the seismic vulnerability of monumental edifices. Switzerland has a diverse collection of monumental buildings. Sacred constructions, which constitute the majority of the heritage buildings, are to be dealt with at first. Developing a generic method that is applicable to all sacred edifices is difficult because they are significantly different from each other. In the poster, we present a method based upon structural units that can be found in every sacred building. At present, this method is applied to only Pre-Romanesque and Romanesque buildings; it will be extended to further periods of art history in the future. The structural behaviour of the identified structural units under seismic loadings is analysed and compared with the dynamic response of whole edifices. This enables the assessment of the relationship between the seismic response of a given building and that of the composing units.

## CS3: Applications of the EMS-98 and Related Future Evolutions
Level 2

### BRIDGING A GAP BETWEEN SEISMOLOGISTS AND ENGINEERS: POSSIBLE RESTRUCTURING OF THE INTENSITY SCALE(S) – ID 571

*H. Sandi, Institute of Geodynamics of the Romanian Academy, Romania*

The paper starts from some basic requirements, desired to be fulfilled by a more thorough approach to intensity assessment: - compatibility between the approaches adopted by seismologists and engineers; - recognition of relevance of severity measures based on processing of instrumental data, and consideration of methodological implications; - recognition of differences of the destructive potential of ground motion for various spectral bands (eventually for different directions too); - the interest for a flexible approach to the degree of detailing of intensity estimates (relating e.g. such estimates to various different spectral bands); - recognition of possible relevant reevaluation of macroseismic information on past earthquakes, reprocessed on the basis of modern concepts concerning especially the spectral content of ground motion; - the complex nature of seismic vulnerability (keeping in view the influence of the spectral content of ground motion, the evolutionary nature of vulnerability due to the cumulative nature of earthquake effects etc.).

The paper is intended to provide corresponding proposals for a more consistent approach to the assessment of seismic intensity. It is proposed to consider an intensity scale structure relying primarily on the postulation of instrumental criteria, making use of accelerographic information. These criteria are designed to be flexible, going up to the estimate of intensity as related to a definite frequency band and/or direction of ground motion. The relationship with macroseismic criteria is considered too, and an increased degree of detailing is proposed, based on the features accepted for instrumental criteria. Some questions raised by the calibration of parameters considered in the frame of instrumental criteria are dealt with too. Post-earthquake survey forms are to be correspondingly extended.

The establishing of a Joint Working Group (JWG) of ESC and EAEE is proposed in this view and specific tasks of its work are proposed.

### DAMAGE SPECTRA AND INTENSITY SPECTRA FOR RECENT VRANCEA EARTHQUAKES – ID 574

*H. Sandi, Institute of Geodynamics of the Romanian Academy, Romania*
*I. S. Borcia, INCERC, Romania*

The developments presented rely, essentially, on the experience of the destructive Vrancea earthquake of 1977.03.04 and of the subsequent strong Vrancea earthquakes of 1986.08.30, 1990.05.30 and 1990.05.31. While first, limited, instrumental strong motion information was obtained for the 1977 event, rich instrumental information was at hand after the latter ones

The experience referred to raised the problem of taking into account the fact that it is reasonable, even necessary, to consider the seismic intensity in connection with the spectral features of ground motion. To be more specific, different intensities may be observed / assessed for different spectral bands. Analytical developments on this subject were presented on several occasions (see e.g. Sandi & Floricel, 11 ECEE, where several alternative intensity measures based on instrumental data were dealt with). Global intensities and, alternatively, intensity spectra, could be determined on this basis.

Subsequently to the 1977 event, an in-depth engineering macroseismic survey was performed in Bucharest (main goal: to provide basic data for a realistic microzonation of the City). A main outcome of the survey referred to consisted of the determination of statistical damage spectra for several areas of Bucharest. This put to evidence, in agreement with the accelerographic data available, the fact that the seismic intensity tended to be higher for longer period spectral bands than for shorter period ones.

The paper presents some of the statistical damage spectra referred to and, for comparison, intensity spectra (corresponding to alternative definitions of intrumental data based intensities) for the case of the 1977 event. Richer homologous data of this kind are presented and discussed for the subsequent events, for which more records were at hand.

Possible implications for the development of an up to.date intensity scale, relying also (possibly mainly) on instrumental data and considering intensity estimates in spectral terms are presented.

## A NATO PROJECT ON DERIVING IMPROVED (INSTRUMENTAL) CRITERIA FOR SEISMIC INTENSITY ASSESSMENT – ID 581

*H. Sandi, Institute of Geodynamics of the Romanian Academy, Romania*

A project referred to as "Quantification of earthquake action on structures" was initiated in the frame of the NATO Programme "Security through Science". The participating institutions are from Romania (coordination), Russia and Republic Moldova.

The main goal of the project initiated is to develop up-to-date instrumental criteria for the assessment / quantification of the intensity of seismic ground motion, taking into consideration the advantages of accuracy of instrumental data (when available) and the fast increasing number of accelerographs. The main startpoints of the project are represented by some analytical developments on instrumental criteria, that should be better suited for intensity assessment, as well as by the outcome of statistical analysis of some direct instrumental data (PGA, PGV, PGD) and of some derived parameters, against macroseismic estimates.

The main objectives proposed initially are as follows: - definition of alternative criteria for assessment of seismic intensity on the basis of instrumental (accelerographic) data; - correlation analysis of the different definitions referred to, a database of actual strong motion accelerograms, and calibration of specific parameters; - reconsideration of macroseismic intensity assessment techniques, with explicit consideration of the spectral characteristics of ground motion (and, consequently, of the dynamic characteristics of building samples representing the basis of post-event surveys); - possible reconsideration of the structure of intensity scales, adopting in the longer term instrumental criteria as primary criteria and macroseimic criteria as secondary ones; - definition of vulnerability characteristics for buildings and other structures accounting for the spectral ground motion characteristics; - experimental application of developments. Besides this, a quantitative method of estimation of seismic effect on the basis of macroseismic data is offered: Two independent operators transform the field of macroseismic parameters into the field of seismic intensity using informatics theory and hypothesis validation.

## OVERVIEW OF MACROSEISMIC ROUTINES IN PORTUGAL – ID 698

*P. Alves, Inst. de Meteorologia, IP., Portugal*
*F. Carrilho, Inst. de Meteorologia, IP., Portugal*

Portugal mainland and Azores Archipelago have been episodically suffered the consequences of catastrophic seismic events. In the Madeira Islands some felt events are also known but not reaching high intensities. The well-known 1755 event and the 1757 event in the Island of S. Jorge in the Azores are very good examples of the dynamic of the seismicity in the territory of Portugal. The 1755 event forced, more then any other, the development of a rational consciousness about this phenomena and the extensive works concerned with it are seen as precursors in the Modern Age. In this work, an overview of the macroseismic works and studies developed in Portugal is intended, as well the state-of-the-art. New methodologies in progress for the integration of macroseimic information on the seismic database are exposed.

## USGS "DID YOU FEEL IT?" COMMUNITY INTERNET INTENSITY MAPS – ID 1087

*D. Wald, U.S. Geological Survey, United States*
*V. Quitoriano, U.S. Geological Survey, United States*
*J. Dewey, U.S. Geological Survey, United States*

The U.S. Geological Survey Community Internet Intensity Map (CIIM) is an automatic web-based system for rapidly generating seismic intensity maps based on shaking and damage reports collected from Internet users immediately following earthquakes. Until recently, the automatic mapping capability has been restricted to the United States and U.S. territories; intensity observations are grouped, averaged, and plotted according to Zip-code regions. We have implemented this system for international data collection, triggered by events of M>5.5 or those significantly reported. We enable users from to select their country and city from pull-down menus. The resolution for automatic intensity assignment outside of the U.S. is at the level of individual cities, which we color-code to the CII value and map as a circle. Although the international CIIM has been available only recently, we have received thousands of responses for European, African, Asian, Middle Eastern, Central and South American, and Caribbean earthquakes. The international CIIM data rapidly confirm earthquake occurrence for us at the National Earthquake Information Center, giving a quick indication of the extent and nature of shaking effects. These intensity data are also automatically used as constraints in our global predictive ShakeMap system, which is the hazard input for our prototype Prompt Assessment of Global Earthquakes for Response (PAGER) system. We expect the global intensity database will prove useful for regional attenuation and other studies. We nonetheless see potential for improving the current international CIIM. The procedure is strongly conditioned by U.S. traditions of macroseismic data interpretation; we envision collaboration with non-U.S. macroseismologists to make the product more useful in non-U.S. contexts. Questionnaires in the native language of the source region would clearly facilitate collection of data globally. CIIM can be found online at http://earthquake.usgs.gov.

## PROJECT OF RUSSIAN SEISMIC INTENSITY SCALE RIS - 04 – ID 1291

*F. Aptikaev, Institute of Physics of the Earth, RAS, Russian Federation*
*I. Ananyin, Institute of Physics of the Earth, RAS, Russian Federation*
*Y. Berzhinsky, Institute of the Earth's Crust, RAS, Russian Federation*
*J. Eisenberg, Russian Association on Earthquake Engineering, Russian Federation*
*O. Erteleva, Institute of Physics of the Earth, RAS, Russian Federation*
*M. Klyachko, Center of Earthquake Engineering, Russian Federation*
*V. Pavlenov, Institute of the Earth's Crust, RAS, Russian Federation*
*E. Rogozhin, Institute of Physics of the Earth, RAS, Russian Federation*
*S. Sherman, Institute of the Earth's Crust, RAS, Russian Federation*
*G. Shestoperov, Railway University, Russian Federation*

In 2004 new Russian seismic intensity scale is developed by five research institutes. This scale has both macroseismic and instrumental parts. The typical errors of previous scales are estimated. Macroseismic scale is based on response of follow object groups: buildings, people, household articles. For these objects the statistical properties are determined. Another group of objects has not estimation of standard deviation or this value is to large. This group contains networks (water-supply, electricity, sewage etc.), transport- constructions and natural phenomena on the Earth surface. Special group is seismological data: earthquake magnitude, faulting type, distance between source and point of observation and ground condition at this point. For the each object group is determined the intensity interval for calculation. The relations to estimate mean intensity using data of equal objects and different ones are proposed. The errors of results are estimated. Special attention is paid to instrumental part of seismic intensity scale. It is shown that many of suppositions used by developing of instrumental scales are wrong. Improved empirical relation intensity/wave parameters are obtained. The calculations are provided for amplitudes of acceleration, velocity, displacement, acceleration + duration, seismic wave power. Standard deviation of log acceleration is 0.39 dec. log. Correlation coefficient is R=0.83. Accuracy of approximation line is about 0.08 dec. log. When duration of seismic vibrations is taken into account, the coefficient of correlation growths up to R=0.90. The same correlation coefficient is between intensity and log wave power W (W=VA).

### DAMAGE DESCRIPTION FOR EARTHQUAKE RISK ASSESSMENT – ID 1419

*J. Schwarz, Bauhaus-University Weimar, EDAC, Germany*
*L. Abrahamczyk, Bauhaus-University Weimar, EDAC, Germany*
*M. Leipold, Bauhaus-University Weimar, EDAC, Germany*
*T. M. Swain, Bauhaus-University Weimar, EDAC, Germany*

Vulnerability functions are the key elements for reliable seismic risk and loss assessment studies providing the opportunity to predict the distribution of damage depending on the severity of shaking. A refined description of damage grades which might be suitable for a general harmonization is given by the European Macroseismic Scale EMS-98. Therein, five damage grades are distinguished for structural and non-structural elements of both masonry and RC type buildings. Their respective definitions are to enable a reasonable distinction between the damage states and a relatively reliable assignment of a global damage grade, DG(EMS-98). Despite the fact that the definitions of the EMS-98 are based on the results of conducted damage surveys, the global damage grade DG(EMS-98) is not sufficient for the interpretation of observed damage patterns. A further refinement in the sense of a local damage grade LDG is desirable and can be realized by analytical "push-over" approaches. Results of these equivalent non-linear calculations of structural models are capacity curves. For a given level of seismic action the associated damage pattern can be predicted (assuming that a realistic structural model is available). In case of RC structures, local damage grades LDG (separately for structural and non-structural elements) are derived from the behavior of both working materials (steel and concrete) within the RC frame elements' plastification zones, which are modeled with fiber elements. As a whole, six damage states are required to cover the most probable failure types. For masonry infill walls a similar procedure will be applied. Results are presented for simplified 2D-models derived from predominant building types in Germany and Turkey. In addition, it is discussed how these analytical results and different levels of damage description can be used to derive the most probable vulnerability class according to the empirical EMS-98 approach.

## CS4: Strong Motion : Use and Modelling
Level 2

### STOCHASTIC SIMULATION OF STRONG MOTION RECORD FROM THE 26TH DECEMBER 2003 BAM EARTHQUAKE – ID 14

*A. Nicknam, Iran Universiyt of Science and Technology, Iran (Islamic Republic Of)*
*A. Yazdani, Iran Universiyt of Science and Technology, Iran (Islamic Republic Of)*
*S. Yaghmaei, Iran Universiyt of Science and Technology, Iran (Islamic Republic Of)*

Acceleration time histories, recorded during the destructive 26th December 2003 (M 6.6) Bam earthquake, have been simulated using a stochastic point source modeling technique proposed by Boore (Boore 1983, 2002). According this method simulate Bam earthquake in Abaragh station with 52 km and compare time series and acceleration and velocity and displacement spectra in simulated and observed earthquake and perceive good agreement between simulated and observed earthquake which confirm that selected source parameters were satisfactory reliable. Also the sensitivity of the PGA to the anelastic attenuation factor, Q(f), is studied.

### ENGINEERING SOURCE MECHANISM MODEL FOR SIMULATING STRONG MOTION ACCELEROGRAMS – ID 89

*R. N. Iyengar, I.I.Sc, India*
*S. T. G. Raghukanth, I.I.T, India*

Specification of realistic ground motion time histories in the near source region is a problem of interest in earthquake engineering. It is recognized that code-based smooth spectral shapes and compatible accelerograms do not incorporate spatial variability arising out of fault orientation, rupture randomness and other parameters. Our understanding of safety of structures near active faults may be sensitively dependent upon some of these factors. Moreover, nonlinear analysis of structures demands ground motion histories that are not artificially filtered to remove long period components. Available three-dimensional seismological models are displacement oriented and do not easily lead to strong motion accelerograms (SMA) in the near source. On the other hand methods that simulate acceleration treat the problem to be one-dimensional, assuming a point source. The present paper addresses the problem, in three dimensions, to propose a new engineering source model for simulation of SMA. Seismological concepts and engineering approximations are combined to retain contributions from all frequencies. The target region is modeled as layered elastic half-space. The moment field on the rupture plane is modeled as a product of space and time functions. Such decomposable moment fields for six past earthquakes are determined by minimizing the mean square error, using available recorded SMA data. It is found that the computed spatial component in each case can be modeled as a stationary random field. Temporal components of all the events are oscillatory transients, with typically similar spectra. Estimating accelerations at stations deliberately kept out of the modeling exercise validates the model. Based on these results, a simplified statistical model is proposed for simulation of SMA. This can generate samples of realistic acceleration time histories near active faults, in urban areas, with no recorded past data. Numerical results are presented for the Kutch, India earthquake of 26th January 2001, to illustrate the model.

### OCCURRENCE OF VELOCITY PULSES IN NEAR-SOURCE GROUND MOTIONS – ID 117

*I. Iervolino, University of Naples - Stanford University, Italy*
*C. A. Cornell, Stanford University, United States*

Near-source ground motion records affected by “directivity” may show unusual features in the signal resulting in low

frequency cycle or half cycle pulses in the velocity time-history, especially in the fault-normal component. Such an effect causes the seismic demand for structures to deviate from that of, so called "ordinary" records. This circumstance may be particularly threatening for structural engineering applications if it is not properly accounted for. In fact, current attenuation laws are not able to capture such effects well if at all and therefore, Probabilistic Seismic Hazard Analysis (PSHA) is not able to predict this peculiar spectral shape. This failure may possibly lead to an underestimation of, in particular, the nonlinear demand. Accounting for pulse-type records in earthquake engineering practice should be reflected both in the PSHA and in the record selection for seismic assessment of structures; all these applications require a probabilistic model for the occurrence of pulse-like records. Herein such model is proposed on an empirical basis; an expert-identified set of pulse-like fault-normal ground motions is used. The independent variables are chosen from those considered by seismologists to affect the amplitude of directivity pulses. Issues related to the dataset, explanatory power of the proposed model and its possible implementations in Performance Based Seismic Assessment (PBSA) are also discussed.

### A METHOD TO THE DETERMINATION OF SYNTHETIC INTENSITY MAPS. APPLICATION TO THE MERANO EARTHQUAKE – ID 213

*I. Ferrer, Universidad Politécnica de Valencia, Spain*
*E. Faccioli, Politecnico di Milano, Italy*

The present study deals with a method for obtaining synthetic intensity maps of a seismic region. The method consists of simulating earthquakes by Hisada's (1994) method. Using the focal mechanism solution and an appropriate source function for the earthquake at study, by Hisada algorithm one can compute synthetic ground motions (e. g. in terms of velocity) over the entire region of interest. Using a correlation between peak ground velocity and macro-seismic intensity, a synthetic intensity map can be constructed. An application to an earthquake located on the Alps region, the Merano earthquake of July 17, 2001 is presented. Firstly, three instrumental records of the Merano earthquake are analysed against published source solution parameters and location, geological conditions, and site effects. Secondly, a numerical simulation of the records has been carried out. In this step, the main difficulty has been the scarcity of data available. Local site conditions -topographic and geotechnical- have been included in the process by a transfer function computed as accurately as possible by the available data. Also, a simulation of ground motion distribution on a regional basis has been made and the intensity distribution has been obtained as previously described, using an empirical correlation based on Italian data. The last step, the construction of the synthetic intensity map has been made using a kriging interpolation. Finally, a discussion of results follows.

### FUNDAMENTAL STUDY OF NON-STATIONARY CHARACTERISTICS OF GROUND MOTION – ID 216

*T. Masatsuki, Tokyo Institute of Technology, Japan*
*F. Sasaki, Tokyo University of Science, Japan*
*Y. Yamamoto, Kajima Corporation, Japan*
*T. Maeda, Waseda University, Japan*
*M. Ohori, Tokyo Institute of Technology, Japan*

Earthquake ground motion has non-stationary characteristics, which may depend on magnitude, geology, distance, and so on. It should affect responses and damages of structures, however, compared with spectral amplitude characteristics, modeling spectral phase characteristics for design input motions has not been studied in detail and is still a challenging task. In order to evaluate non-stationary characteristics quantitatively, we define a parameter (GammaTgr2) that reflects relative strength of group delay time on non-stationary characteristics. GammaTgr2 varies from 0.0 to 1.0. To show the validity of GammaTgr2, we examine the fundamental characteristics of GammaTgr2, using idealized waveforms. GammaTgr2 is about 0.0 for stationary sine waves and 1.0 for log sweep waves, which have strong non-stationary characteristics. GammaTgr2 is a relevant measure for strength of non-stationary characteristics. Then we discuss the effects of epicentral distance and soil characteristics on GammaTgr2, using ground motion records of one earthquake, the Off Miyagi earthquake on May 26th, 2003 (Mw 7.0). GammaTgr2 tends to be larger at lowlands than at highlands. The variance of GammaTgr2 becomes large according to the epicentral distance. We also discuss the effects of soil characteristics on GammaTgr2, using earthquake ground motion records of many earthquakes observed during 1996-2005 in Japan. The records that have strong non-stationary characteristics are more often observed in the soft soil ground than in the stiff soil ground.

### WAVELET-BASED ANALYTICAL MODEL ACCOUNTING FOR NEAR-FIELD EFFECTS OF VRANCEA EARTHQUAKES – ID 225

*A. Zaicenco, Institute of Geophysics and Geology, Moldova, Republic Of*
*A. Vasile, Institute of Geophysics and Geology, Moldova, Republic Of*

The basic features of the near-field earthquake ground motions are short duration, strong directivity, and low-frequency impulsive motion in the velocity time-history. An analytical model for the representation of near-source strong ground motions based on Gabor wavelet is applied to August 30, 1986 Vrancea earthquake. Simple physical meaning of the input parameters of the model represents adequately the impulsive character of the near-field records, and succesful simulation of the entire data set proves the potential of the method for use in ground-motion simulation. The modified Gabor wavelet is capable of capturing the time-history and response spectra characteristics of the coherent component of the near-field records. The incoherent component of ground-motion is simulated with the stochastic approach, providing good compatibility of the resulted linear and equal-ductility non-linear response spectra.

### UNIFORM HAZARD SPECTRA – ID 235

*S. Stamatovska, Institute of Earthquake Engineering and Engineeriy, Macedonia*

The main objective of these investigations is to present a methodology for determination of linear and nonlinear response spectra and Fourier amplitude spectrum with uniform probability of exceedence by using records of occurred strong earthquakes and a probability approach. Attenuation laws for linear and nonlinear response spectra as well as Fourier amplitude spectra have been defined. They represent empirical functional relationships between the parameters of dynamic response of elastic and elasto-plastic model of a single degree of freedom system and the Fourier amplitude spectrum and the earthquake parameters. For 23 models of a single degree of freedom system with natural periods ranging between 0.05 and 5.0 s, damping of 5% of the critical, there have been defined the attenuation laws for horizontal direction for: • pseudo velocity response spectrum in case of an elastic model; • maximum displacement, maximum acceleration and ductility factor in case of elastic-plastic model with varied ultimate strength expressed as equivalent horizontal force according to the valid regulations for seismic design of high rise buildings in Macedonia, and • Fourier amplitude spectrum. All the attenuation laws have been defined by using the same data bank from records of occurred earthquakes. The attenuation laws have been applied in seismic hazard analyses performed for the city of Skopje. For return periods of 95 and 475 years, there have been defined uniform hazard: • pseudo velocity linear spectra, • nonlinear ductility factor spectra, and • Fourier amplitude spectrum. With this, the methodological approach for definition of uniform hazard spectra has been verified.

Keywords: attenuation law, response spectrum, acceleration, displacement, ductility factor, Fourier amplitude spectrum, seismic hazard analysis, uniform hazard spectra.

### TOWARDS THE CHARACTERIZATION OF STRONG GROUND-MOTION IN THE MEXICAN SUBDUCTION ZONE – ID 256

*D. García, Dpto. Geofísica y Meteorología, UCM, Spain*
*S. K. Singh, Instituto de Geofísica, UNAM, Mexico*
*M. Herraiz, Dpto. Geofísica y Meteorología, UCM, Spain*

Seismic hazard along the Mexican subduction zone is ruled by thrust-faulting interplate earthquakes and normal-faulting intermediate-depth (35<H<150 km) inslab events. In this study we use an extended dataset comprising more than 400 records from 40 interplate earthquakes (Mw 5.0-8.0) to develop strong-motion equations for the horizontal component of pseudoacceleration (PSA) response spectra (5% damping), peak ground acceleration (PGA), and peak ground velocity (PGV). These equations are derived for free-field rock (NEHRP B) sites located south of the Mexican Volcanic Belt. We compare this model with that proposed for Mexican inslab earthquakes in a previous study. Our results show larger amplitudes in the epicentral area from inslab events than from interplate events, a consequence of higher stress drops during the former type of earthquakes. These differences increase with magnitude and frequency, reaching the largest inslab events PGA values almost three times larger than those from interplate ones. At increasing distances, however, the slower decay of thrust events results in expected motions larger than those from inslab ones. This behaviour may extend the potential damaging from interplate earthquakes beyond 200-250 km. The derived relations improve the seismic characterization of this subduction margin and predict ground motions in reasonable agreement with studies based on other subduction zones.

### SEISMIC WAVEFIELD ANALYSIS IN MEXICO CITY USING ACCELEROMETRIC ARRAYS – ID 395

*M. Cardenas-Soto, Faculty of Engineering, UNAM, Mexico*
*F. J. Chavez-Garcia, Institute of Engineering, UNAM, Mexico*

We have analyzed data from one earthquake (14.09.95; M=7.3) recorded by the Mexico City Accelerographic Array (75 stations). We first analyzed the filtered records in a several frequency bands in order to identify the predominant waves. Then, we used frequency-wavenumber analysis (f-k) to determine the velocity and direction of propagation of the recorded waves. Given that we require the signals to be similar among the stations, we could not use all stations together, and divided the stations into 7 subarrays, for which all stations are located on similar soil conditions and dominant period (T0) is almost constant. The results show that T0 of surficial clay layers is a limit separating two period regions. For periods longer than T0, the wavefield is composed of surface waves. Energy at periods larger than 2T0 is guided by the crustal structure (40 km thick); phase velocity and direction of propagation for the wavefield coincide with the fundamental mode of surface waves propagating from the epicenter. The wavefield at periods between T0 and 2T0 is guided by the upper 2-3 km of volcanic sediments in central Mexico. In this period range, the dominant propagation mode is still surface waves, but they do no longer come from the epicentral region. These surface waves appear to have been diffracted by the southern boundary of the Mexican Volcanic Belt. For periods smaller than T0, ground motion is uncorrelated among the stations, and it becomes impossible to determine a dominant propagation mode. At these short periods, response is dominated by the very local amplification due to the soft soils. Our results indicate that seismic response of Mexico City results from surface waves guided by the depth and intermediate crust structure interacting with the very local response of the soft surficial clay layer.

### SEISMIC DURATION EFFECTS ON THE VULNERABILITY OF BUILDINGS – ID 402

*N. Nanos, Structural Mechanics, UK*
*A. Elenas, Structural Mechanics & Earthquake Engineering, Greece*

Post-earthquake damage estimation has become important in the last decades; there has been a worldwide interest and considerable financial expenditure was made in the quest for accurate post-earthquake damage estimation in new or existing buildings. This signifies the need for an in-depth study of the interrelation between the seismic characteristics and the degree of damage a building suffers after an earthquake, leading to the creation of an accurate mathematical model.

This paper presents a methodology for the identification of the interdependency between several intensity parameters and the vulnerability of buildings. First, several artificial accelerograms have been evaluated, compatible with the design spectra of the Greek antiseismic code (EAK). They have been chosen to have a wide range of strong motion duration and for each one of them the values of peak ground acceleration (PGA), spectral energy (SE), Housner's spectral intensity (SI) and Arias intensity (AI) have been calculated. Next, nonlinear dynamic analyses have been conducted to evaluate the seismic response of an examined building. The focus is on the Maximum Inter-Storey Drift Ratio (MISDR), which has been chosen as global damage indicator. In addition, several vulnerability curves have been calculated based on the different accelerograms. The curves have been derived using appropriate scaled acceleration time-histories in order to incorporate a wide range of damage degrees (from negligible to severe). Finally, their interrelations with the seismic intensity parameters have been studied.

This procedure has been applied on a 10-storey reinforced concrete frame building, designed after the rules of the recent Eurocodes (EC2 and EC8). The numerical results show that the strong motion duration has poor interrelation with the vulnerability degree of the building, in contrast to the remaining examined seismic intensity parameters, that exhibit a more noticeable relation.

### ALTERNATIVE SPECTRAL INTENSITY PARAMETERS – ID 404

*A. Elenas, Structural Mechanics and Earthquake Engineering, Greece*
*V. Bogdanou, Structural Mechanics and Earthquake Engineering, Greece*

This study describes numerically the interdependency between spectral intensity (SI) parameters of seismic excitations and damage indices. SI parameters have been used both, in their original and some modified definitions. Additional to the spectral intensities, some general ground motion parameters are also used for characterising the seismic excitation. The SI after Housner, Hidalgo/Clough, Kappos, Matsumura, Nau/Hall and Martinez-Rueda are evaluated. A modified definition of the spectral intensities is provided through the replacement of the pseudo-velocity spectra (original definition), with the seismic absolute energy spectra. In addition, the general ground motion parameters such as the peak ground acceleration, the strong motion duration after Trifunac/Brady, the spectral seismic input energy and the spectral pseudo-acceleration have been calculated. On the other hand, both, structural and non-structural damages are considered, expressed by overall damage indices.

After the evaluation of the seismic parameters, nonlinear dynamic analyses are conducted to furnish the damage status. The interrelationship between the seismic parameters and the damage indices is described by correlation coefficients. This investigation is carried out for a reinforced concrete plane frame system designed after the Eurocodes 2 and 8. The aim is to find out the general and spectral characteristics of the accelerograms that exhibit the strongest influence on structural and non-structural damages.

Numerical results have shown that the examined general seismic parameters exhibit commonly poor or fair correlation with the damage indices, whereas the SI parameters furnish good correlation. Among the examined spectral intensities, those defined by Housner and by Nau/Hall gave the strongest correlation with the damage indices. Additionally, results have revealed that the modified spectral intensities are a suitable alternative to the original definitions. All these results lead to conclude that the spectral intensities are reliable descriptors of the seismic damage potential.

### APPLICATION OF TIME-DOMAIN STOCHASTIC MODELLING FOR SEISMIC DESIGN PARAMETERS – ID 416

*A. Naiieri, Lar Consulting Engineers, Iran (Islamic Republic Of)*

For areas with less recorded accelerograms, time-domain stochastic modelling is used for generating site-specific accelerograms and peak parameters such as peak ground acceleration, peak ground velocity and smoothed acceleration response spectra. In this work, the application of time-domain stochastic modelling in site-specific seismic hazard assessment is discussed. It is shown, through a parametric sensitivity analysis, that the synthetic response spectra are sensitive to quality factor (Q0) for periods less than 0.5 seconds, to kappa for periods less than about 1.0 seconds, and to stress parameter for the whole period range of interest in engineering application, i.e. 0.04 to 2.5 seconds. In the current state, near-field effects such as rupture directivity could not be modelled in this approach. Directivity becomes significant for periods larger than 0.6 seconds. Horizontal components are synthesized and vertical components could be calculated using the Ver/Hor ratio. The method is basically a deterministic approach to ground motion parameter estimation, and is, accordingly, applicable to MCE seismic level in design. By applying the same method, a suit of prototype accelerograms could be synthesized, which after proper scaling with probabilistically derived target spectra, could be used for design basis and maximum design levels, as well. However, in this case, the source-to-site distance is not a well-defined parameter. An appropriate distance could be obtained by trial values within 10 to 30 km of the site. Another approach is to use the normalized stochastic spectrum with further scaling to match the design peak ground acceleration.

### STRONG GROUND MOTION SIMULATION OF 2005 GHESHM ISLAND EARTHQUAKE, SOUTH OF IRAN. – ID 417

*H. Ghasemi, IIEES, Iran (Islamic Republic Of)*
*M. Zare, IIEES, Iran (Islamic Republic Of)*

An earthquake that measured 6.2 on the Richter Scale struck the southern boarder of the Iranian territory on November 27, 2005 at 10:22:19(UTC). The earthquake killed over 8 and injured more than 20 people. The main shock was recorded by 11 SSA-2 accelerographs installed by Iranian Strong Motion Network (ISMN). In this study the Stochastic Finite-Fault method is used to simulate the acceleration time histories. The method generalizes the stochastic ground motion simulation technique, developed for point source, to the case of finite faults, in which the ground motion amplitudes are simulated as a summation of stochastic point source. Geometrical spreading and regional inelastic attenuation are included in the model and the last one is estimated using nonparametric approach based on the available accelerograms .The strong motion simulations are performed by adjusting the sub-fault size to calibrate the simulation model against recorded ground motions. In this way the length of the fault is taken as 25 kilometers and it's width as 18 kilometers, and the fault plane is divided in to 5×3 elements. Regarding that site amplification functions play an important role in the simulation process, site specific amplification function is estimated by the horizontal to vertical ratio technique. A quite satisfactory agreement is found between the simulated amplitude Fourier spectra and the recorded data at frequencies of engineering interest (0.1-20 Hz) including the capability of the method to reproduce the salient ground motion characteristics.

### GENERATION OF NEAR-FIELD GROUND MOTIONS IN TEHRAN FROM FUTURE LARGE EARTHQUAKES IN THE WESTERN ALBOR – ID 448

*H. Zafarani, University of Tehran, Iran (Islamic Republic Of)*
*A. Noorzad, University of Tehran, Iran (Islamic Republic Of)*
*K. Bargi, University of Tehran, Iran (Islamic Republic Of)*

A large earthquake in the Western Alborz Seismic Zone (WASZ) is likely to cause great loss of life and severe damage to construction in and near the epicentral zone. The most important population area is Tehran, a city of more than eight million inhabitants, lies in the vicinity of some major active faults. Unfortunately, the sparse strong-motion data set presently available from existing faults in Tehran area makes estimation of ground motion during future earthquakes quite a challenge. In this study, we simulate time histories at the Greater Tehran Area, for scenario earthquakes along most active and hazardous faults in the WASZ. Three fault planes assumed for the simulations are as follow. The Mosha fault has a length of 75 km and width of 27 km, corresponding to an event of M 7.4. The North Tehran fault has a length of 58 km and width of 22 km, corresponding to an event of M 7.2, while the Ray fault has a length of 29 km and width of 14 km, corresponding to an event of M 6.7. In order to synthesize strong ground motion seismograms, we are using the stochastic finite-fault method of Beresnev and Atkinson (1997). The applied finite-fault approach allows one to define independently a variety of rupture scenarios on the fault plane by varying the hypocenter location, rupture velocity, fault plane geometry, slip distribution and stress drop. Therefore, we can create worst-case scenarios for the chosen sites. Simulations are made for representative soil profiles for each of the sites, as well as for reference bedrock conditions (at the base of the soil profile). We compare peak horizontal acceleration (PHA) with attenuation laws proposed for the region. Our results encourage the application of the method as a supplementary tool for site-specific strong ground motion prediction in Tehran area.

### DEVELOPMENT OF A FUNCTIONAL-FREE GROUND MOTION ATTENUATION RELATION – ID 449

*G. Sobhaninejad, University of Tehran, Iran (Islamic Republic Of)*

The main objective of proposing different attenuation laws is to establish the relation of ground motion parameters through investigation among seismic data. Based on these data the appropriate semi imperial relation between ground motion parameters is established. So the noticeable difference between attenuation relations lies in their functional form which is due to unknown and complex correlation between the ground motion parameters and characteristics of data used in establishing attenuation law. These complexities mislead us in estimation of actual correlation among ground motion parameters. In this article we use "Generalized Approxiamtor" concept by means of Adaptive-Network-Based Fuzzy Inference Systems (ANFIS) to omit prevalent functional form of attenuation relations and importing characteristics of data in calculating attenuation relation. The Adaptive-Network-Based Fuzzy Inference Systems (ANFIS) is used as a powerful tool for estimating relations between parameters of ground motion. By means of this concept the functional form of attenuation laws omitted and results compared with other attenuations relations. In order to improve the rate of ANFIS training convergence, the hybrid learning rule is used. The Functional-Free attenuation relations for earthquake horizontal and vertical peak ground acceleration are developed for earthquakes in Europe and Middle East caused by shallow crustal earthquakes with magnitude Mw$\geq$5 and distance to the surface projection of the fault less than 100 km.

### NEXT GENERATION ATTENUATION (NGA) GROUND MOTION PREDICTION RELATIONS: CAN THEY BE USED IN EUROPE? – ID 458

*K. Campbell, EQECAT, Inc., United States*
*Y. Bozorgnia, Pacific Earthquake Engineering Research Center, United States*

We are one of five teams developing ground motion prediction (attenuation) relations for PGA and spectral acceleration as part of the PEER Lifelines Next Generation Attenuation (NGA) Project. Each team independently selected recordings from a strong-motion database of worldwide earthquakes from shallow active tectonic regions developed specifically for the project. As part of our selection criteria, we eliminated aftershocks and poorly recorded earthquakes using a scheme that required smaller events to have a larger number of recordings than larger events. This

resulted in the selection of 1561 recordings from 64 earthquakes with moment magnitudes (Mw) ranging from 4.3 to 7.9 and rupture distances (Rrup) ranging from 2 to 165 km. One of the biggest challenges was to develop a functional form that accounted for a change in magnitude scaling around Mw 6.5-7.0 predicted by recent Mw$\geq$7.0 earthquakes in California, Turkey, Taiwan and Alaska without predicting extreme over-saturation of short-period ground motions at close distances and large magnitudes. The authors were the first to propose aspect ratio (rupture length divided by rupture width) as a parameter that could account for this phenomenon; however, a comparison of aspect ratios from the NGA database with those of faults modeled by the USGS indicated that there might be a bias in the NGA aspect ratios or the USGS source model that prevented such a relationship from being used in a predictive sense. Aspect ratio will be reconsidered once these discrepancies are resolved. The final decision was to use tri-linear magnitude scaling with slope breaks at Mw 5.5 and 6.5. Other parameters in the model include average 30-m shear-wave velocity (Vs30), sediment depth (both shallow and 3-D basin effects), hanging-wall effects, and nonlinear soil response in terms of Vs30 and rock PGA. We provide evidence to support use of our NGA attenuation relations in Europe.

## GROUND MOTION SIMULATION BASED ON WAVELET TRANSFORM AND NEURAL NETWORKS – ID 477

*A. Arash Zandieh, university of tehran, Iran (Islamic Republic Of)*

In earthquake-resistant design of structures, for certain structural configurations and conditions, it is necessary to use accelerograms for dynamic analysis. Accelerograms are also needed to simulate the effects of earthquakes on a building structure in the laboratory. A new method of generating artificial earthquake accelerograms is presented through adroit integration of wavelets and neural networks.wavelets. A counterpropagation (CPN) neural network model is developed for generating artificial accelerograms from any given spectral acceleration spectrum.Using the spectrum as network input means an accelerogram may be generated for any geographic location regardless of whether earthquake records exist for that particular location or not.The proposed CPN-wavelet model is trained using sets of accelerograms and tested with additional sets of accelerograms.Given the limited set of training data, the result is quite remarkable.

## BROADBAND GROUND MOTION SIMULATION OF ROMANIAN EARTHQUAKES USING EMPIRICAL GREENS FUNCTION METHOD – ID 506

*N. Poiata, National Center for Seismic Risk Reduction, Romania*
*H. Miyake, Earthquake Research Institute, University of Tokyo, Japan*

We simulated broadband ground motions for the intermediate-depth subducting earthquakes from the Vrancea seismic region, Romania, using the empirical Green's function method. The method is for simulating both high- and low-frequency ground motions by summing up subevent records to follow the source scaling and the omega-square spectral model (Irikura, 1986). We first estimated strong motion generation area within a total rupture area of the October 27, 2004 moderate earthquake (Mw 5.8), by comparison of the synthetic waveforms of displacement, velocity, and acceleration with the observed one. The stress drop of the area is estimated to be about 10 MPa, which is similar to that for the inland crustal earthquakes. We then modeled the strong motion generation area for one of the disastrous earthquakes in Romania from March 4, 1977 (Mw 7.4), using the subfault constructing the source parameters of Mw 5.8 earthquake. To simulate the unique record at Bucharest capital city, the rupture is assumed to propagate from the northeast bottom of the area with 50-MPa stress drop. Our estimates support the size-dependent stress drop for the intermediate-depth earthquakes of the Vrancea region in the previous study. Broadband ground motion simulations are compared in terms of MMI intensity calculated from the PGA and PGV values of the synthetic waveforms with the observed intensity values. The simulated MMI intensities slightly overestimate except Bucharest capital city.

## CONCEPT AND PROTOTYPE OF STRONG-MOTION DATABASE FOR SELECTING THE INPUT MOTION IN USE OF THE E-DEFENSE – ID 512

*K. Kudo, University of Tokyo, Japan*
*A. Narita, MSS, Japan*

This is a report on current status of a 3-D strong-motion database (SMDB) for providing the input earthquake motion to the 3-D Full Scale Earthquake Testing Facility, so-called E-defense of the NIED in Japan. The SMDB will also be useful for various studies for seismology and earthquake engineering. The basic components of the database, similar to the other databases, are consisted of three tables; those are earthquake data, station data, and waveform data. We decided to use the waveform data format of K-NET as a unified format in the database, because the utility software for K-NET data and the data format are very familiar to the users in Japan. The works of data-registration are still in progress, however, strong- and weak-motion data in Japan during 1987-2004 as well as most strong-motion data in the world have been included in the database. The simulated ground motions for the anticipated earthquakes will be added as well. The major issue to include PGV, PGD and SI for the data-search will be the computation of velocity and displacements or to find low-frequency limit in an integration procedure. We have successfully tried to determine the cutoff frequency semi-automatically associated with attributes and/or quality of data using the shape of response spectra and the empirical relation of source process time. We emphasized the scheme to search data for many objectives.

## ANALYSIS OF ACCELEROGRAPH DATA FROM 5.3 MB EARTHQUAKE OF DECEMBER 14, 2005 AT CHAMOLI, INDIA – ID 513

*M. Shrikhande, IIT Roorkee, India*

A moderate earthquake of magnitude 5.3 (mb) struck the Northern parts of India on December 14, 2005. This earthquake had its epicenter located at (30.48 E, 79.25 N), near Chamoli district in lower Himalayas. This event was recorded by 8 new generation digital accelerographs recently deployed in the region. An analysis of the recorded accelerograms is presented in this paper and the estimated strong motion parameters are correlated with the macro earthquake parameters and local conditions. The implications of the ground motion characteristics on the seismic hazard assessment in Himalayan region are discussed.

## EMPIRICAL EVALUATION OF ATTENUATION RELATIONS OF PEAK GROUND ACCELERATION IN THE ZAGROS AND CENTRAL IRAN – ID 558

*A. Mahdavian, Power and Water University of Technology (PWUT), Iran (Islamic Republic Of)*

For special structures requiring more than the use of simplified seismic design procedures, a formal seismic hazard analysis (SHA) normally needs to be conducted on the prospective site before design begins. Inherent in a SHA are geologic, geophysics and seismological investigations that provide site-specific information pertaining to the design ground motion. This information is required if a rigorous dynamic analysis of the proposed structure is to be performed as part of the design process. Although many response quantities are useful, traditionally peak acceleration is most commonly used in engineering applications. This research consists of introducing the attenuation relations of horizontal and vertical acceleration developed in this study based on acceleration data recorded in Iran and introduces different attenuation relations to prepare seismic zonation map of Iran. Site geology influences seismic wave attenuation. An attenuation expression provides a functional relation between earthquake properties or

response quantities and various parameters such as magnitude, soil conditions, site-to-source distance, etc. Because of the earthquake characteristics recorded data, we divided the country into two parts, such as Zagros and Iran minus Zagros (I-R) regions. The result shows a good comparison between recorded data with the outputs of the acceleration based on presented attenuation relations with several magnitudes, distances and different site conditions for this study.

### SIMULATING ACCELEROGRAMS OF THE ZARAND EARTHQUAKE – ID 575

*M. Ashtari Jafari, Tehran University, Iran (Islamic Republic Of)*
*M. R. Hatami, Tehran University, Iran (Islamic Republic Of)*

On February 22, 2005 a powerful earthquake having Mw equal 6.4 caused catastrophic damage in a part of south central Iran near city of Kerman named Zarand. The responsible source for this quake seems to be a reverse fault which its motion type is confirmed by teleseismic focal mechanism solutions also. The earthquake is within a series of large earthquakes in the same province beginning in 1977 and continued by events occurred in 1981, 1998 and the Bam fatal earthquake of 2003. The point to remember about it; is existence of reverse motion unlike the strike-slip motion for the previous recent regional earthquakes. In this study we have used the stochastic finite-fault technique to simulate the Zarand earthquake time histories. Despite the popularity of the point source modeling which may be unable to characterize some features of great earthquakes like source directivity and long duration this method may not only contribute to the above mentioned problems but also to affect the shape of spectra of ground motion. The method discretizes the fault plane into small subfaults and the overall radiation from all subfaults will be enhanced at the observation station. A set of well recorded strong motions around the epicenteral area have been used to fit and compare the simulated to the observed ground recordings and to obtain source parameters. Uncertainty in input parameters and effect of nonlinearity for soil sites is considered. Results show to be sensitive to maximum slip velocity, magnitude and hypocenter location.

### SEISMIC GROUND MOTION MODEL WITH FREQUENCY DEPENDENT MODULATING FUNCTIONS – ID 599

*C. Arunasis, Trinity College, Ireland*
*B. Biswajit, Trinity College, Ireland*

A wavelet based generalized non-stationary seismic ground motion model is proposed in the present study, where the earthquake is modelled as a summation of amplitude modulated stationary orthogonal processes. An exponential envelope function proposed by Shinozuka and Sato is used in the present study for amplitude modulation of each orthogonal process. Each of these processes in frequency domain is represented by a band limited frequency content. Wavelet analysis can identify each of these processes by filtering the orthogonal signal. A wavelet based time-frequency analysis is used to evaluate the energy content of the recorded time history in different frequency bands, where the wavelet coefficients of the recorded accelogram is evaluated using a modified form of the Littlewood-Paley (MLP) basis function. The MLP basis being completely localized in frequency, can evaluated energy in non-overlapping frequency bands. The parameters of the envelope function are evaluated by minimizing the error between the growth in temporal energy of the recorded time history and that obtained from the proposed model in each frequency bands. A local averaging technique is adopted to evaluate the expected value of the square of wavelet coefficients, where the time window width depends upon the central value of the corresponding frequency band. The proposed model can take into account the time varying frequency content of the ground motion. A statistical simulation is then performed using recorded time history of El-Centro ground motion to validate the proposed model.

### CALIBRATION OF THE SPECIFIC BARRIER MODEL TO EAST-CENTRAL IRAN EARTHQUAKES – ID 614

*M. Mousavi, university of Tehran, Iran (Islamic Republic Of)*
*A. Noorzad, university of Tehran, Iran (Islamic Republic Of)*
*H. Zaferani, university of Tehran, Iran (Islamic Republic Of)*

The paucity of high-quality strong motion data for moderate and large earthquakes in east-central of Iran makes it difficult to estimate strong ground motion for earthquake engineering purposes. The Specific Barrier Model (SBM) which proposed and developed by Papageorgiou and Aki (1983;1985) applies both in the "near-fault" and in the "far-field" region, thus allowing for consistent ground-motion simulation over the entire frequency range and for all distances of engineering interest. However, to predict future earthquakes characteristics using the SBM , it is necessary to calibrate the model by well recorded earthquakes. Base on an event by event method, the model is applied to a set of available strong motion database of east-central Iran Earthquakes .Source parameters which control the shape of source spectrum -barrier intervals and local stress drop - are determined as a function of magnitude in the region of interest. Results agree well with study by Halldorsson and Papageorgiou (2005) in which the SBM parameters was determined for earthquakes of different tectonic regions.

### PREDICTION OF PEAK GROUND VELOCITY FOR EUROPE AND SURROUNDING COUNTRIES – ID 631

*S. Akkar, Middle East Technical University, Turkey*
*J. Bommer, Imperial College London, UK*

Peak ground velocity (PGV) has many applications in earthquake engineering, being used in some approaches for constructing response spectra, for the seismic analysis of buried pipelines and in some methods for the assessment of liquefaction potential. Recent research showed that PGV correlates well with the non-linear deformation demands, vindicating the use of this parameter as an indicator of damage potential. However, whilst there are now many ground-motion prediction equations for peak ground and response spectral accelerations, there are relatively few equations for PGV. This has led to the widespread practice of scaling PGV from the 1-second spectral ordinate, which has recently been shown to be unreliable.

A uniformly processed ground-motion data set from Europe and adjacent areas was used to derive new prediction equations for peak ground velocity (PGV). The data set comprises 532 records from 133 events with moment magnitudes ranging between $5 < M < 7.4$. The site classes are divided into 3 categories defined by the upper 30 m shear wave velocity profile. The influence of long-period filter cut-off on the larger and geometric mean horizontal PGV is also discussed. The study explored various alternative functional forms for the prediction of PGV and concludes that the expression with quadratic magnitude dependence and magnitude-dependent geometric decay best represents the variation of PGV within the magnitude and distance ranges covered by the database. The resulting prediction equations are compared with previously derived PGV equations for Europe and for the western US. Significant discrepancies are noted between the new equations and the other expressions, in particular for large magnitude events. This might be attributed to the relatively low amplitude ground velocities recorded during the M7.2 and M7.4 1999 Turkey earthquakes that dominate the large magnitude events in the data set.

### ATTENUATION RELATIONS OF STRONG GROUND MOTION IN JAPAN USING SITE CLASSIFICATION BASED ON PREDOMINANT PERIOD – ID 683

*Y. Fukushima, Ohsaki Research Institute Co., Inc, Japan*
*J. Zhao, Institute of Geological & Nuclear Sciences, New Zealand*
*J. Zhang, Institute of Geological & Nuclear Sciences, New Zealand*
*A. Asano, Shikoku Electric Power Co. Inc., Japan*
*Y. Ohno, Shikoku Electric Power Co. Inc., Japan*
*T. Oouchi, Shikoku Electric Power Co. Inc., Japan*

*T. Takahashi, Shikoku Electric Power Co. Inc., Japan*
*H. Ogawa, Shikoku Electric Power Co. Inc., Japan*
*K. Irikura, Aichi Institute of Technology, Japan*
*P. Somerville, URS Corporatio, United States*

A spectral acceleration attenuation model for Japan is presented in the present study. The data set includes a very large number of strong ground motion records up to the 2003 Off Tokach main and aftershocks. Site class terms, instead of individual site correction terms, are used. The site classes of recording stations are from a recent study on site classification for strong-motion recording stations in Japan according to a classification scheme that has been used in Japanese engineering design. The use of site class terms enables tectonic source-type effects to be identified and accounted for in the present model. The effects of faulting mechanism for crustal earthquakes also are accounted for. For crustal and interface earthquakes, a simple form of an attenuation model (with respect to distance) is able to capture the main strong-motion characteristics and achieves unbiased estimates. For subduction slab events, a simple distance modification factor is employed to achieve plausible and unbiased predictions. The effects of source depth, tectonic source type, and faulting mechanism of crustal earthquakes are significant. The need for magnitude-squared terms is evaluated and the use of magnitude-squared terms reduces the inter-event error further.

## STRONG MOTION PREDICTION USING STATISTICAL GREENS FUNCTIONS AND DAMAGE PREDICTION BASED ON NONLINEAR STRUCTURAL MODELS – ID 723

*N. Ho, Kyushu University, Japan*
*H. Kawase, Kyushu University, Japan*

Quantitative strong motion prediction and damage evaluation of structures is indispensable for future disaster mitigation. We first utilize statistical Green's functions obtained from strong motion data of K-NET, KiK-net, and the JMA Shindo-kei network in Japan to predict strong motions for a large subduction-zone earthquake. To generate statistical Green's functions we need both spectrum and envelope information. We choose to separate Fourier spectra of about 16,000 records into source, path, and site factors. We also determine parameters of the Boore's envelope function for all the accelerograms and separate them into source, path, and site factors as well. As a reference site we use a rock site with the surface S-wave velocity of 3.45km/s. Then we use Irikura-Kamae method of empirical Green's function to sum up statistical Green's functions for a moderate size earthquake ( M6.5) and synthesize them to predict strong motions due to the expected Nankai earthquake of M8.0, a large subduction-zone earthquake in western Japan. We use the same source process assumed by Kamae and Irikura which has three segments and three asperities. We generate statistical Green's functions for all the sites within 400km from the source. The resultant strong motions show similar PGA values of empirical relations and the calculated seismic intensities show similar values as observed in the previous two events. Finally we input these strong motions to dynamic nonlinear structural models. Our nonlinear structural models are unique because they are multiple models with different strengths with different existence ratios. From the theoretical calculations we can determine damage ratios for different types of building. For quantitative prediction we determined model parameters based on the damage statistics in Kobe after the Hyogo-ken Nanbu (Kobe) earthquake of 1995. We found that heavy damage to structures can only be found in the near-source region.

## PRESUMABLE MODELS OF THE NONLINEAR SOIL BEHAVIOR IN NEAR-FAULT ZONES DURING THE CHI-CHI EARTHQUAKE – ID 739

*O. Pavlenko, Institute of Physics of the Earht, Russian Federation*
*K. L. Wen, Institute of Geophysics, Nation. Centr. University, Taiwan*

The Chi-Chi, Taiwan, earthquake (September 1999, Mw=7.6, depth 8 km, the mainshock triggered about 441 strong-motion instruments) is one of the strongest earthquakes during the last years, recorded by a large number of strong-motion devices. Among the obtained records, there are many near-fault accelerograms, showing a clear evidence of the nonlinearity in the soil response. In this study, near-fault accelerograms of the mainshock of the Chi-Chi earthquake at soil sites are simulated (1D simulation), and presumable models of the nonlinear soil behavior are constructed, i.e., stresses and strains induced in the upper meters of the soil layers by the strong motion are estimated. As input signals, synthetic accelerograms, calculated by stochastic finite-fault modeling and calibrated against the data of the Chi-Chi earthquake recorded at rock sites, were taken. In reconstructing stresses and strains, our previous experience in studying soil behavior during the 1995 Kobe and the 2000 Tottori earthquakes was used. The obtained models indicated substantial nonlinearity of the soil response during the Chi-chi earthquake and allowed us to distinguish the area of strong nonlinearity (where the content of nonlinear components in the soil response exceeds 50%, where the strong motion caused changes in rheological properties of the upper soft soil layers, and spectra of oscillations on the surface take the smoothed form close to E(f) f -k) in the vicinity of the fault plane. We defined its approximate size as $\frac{1}{4}$ of the length of the fault plane. Within this area of strong manifestations of soil nonlinearity, the majority of standard computer programs of the soil response estimation would give wrong estimates, whereas, they are applicable beyond this area. We also obtained a similarity in the models of the behavior of similar soils during different strong earthquakes, indicating the possibility of precasting soil behavior in future earthquakes.

## CONSTRUCTION OF 3-D VELOCITY MODEL FOR STRONG GROUND MOTION SIMULATION IN COMPLEX TECTONIC ENVIRONMENT – ID 757

*A. Petukhin, Geo-Research Institute, Japan*
*T. Kagawa, Geo-Research Institute, Japan*

Construction of the 3-D velocity models for the strong ground motion generation in a complex tectonic environment, i.e. subduction zone, is a difficult problem. Popular "stand along" methods, i.e. seismic tomography or the receiver function inversion, suffer from the inversion instabilities and require an intensive constraining of parameters. In this work to construct the 3-D velocity model in a wide area, that includes both the inland areas, covered by seismometers, and the off-shore areas, where seismic observations are scarce, we generalize different kinds of the available information in the studied region. The 3-D velocity model for the area of the Philippine subduction zone in Japan, was constructed from 7 layers: (1) surface low-velocity layer, LV, (2) upper crust, UC, (3) lower crust, LC, (4) mantle wedge, MW, (5) oceanic crust layer, OC, (6) Philippine sea slab, SLB, (7) upper mantle, UM. Next data were used: the off-shore seismic profile (LV, OC), the seismicity (UC, SLB), the 1-D velocity models for the hypocenter determination (LV, UC, LC and MW), the seismic tomography results (LC, SLB), and the gravity anomaly data (LV). In order to validate the developed velocity model, we calculated the P-wave travel times and compared them with the observed times. Average standard deviation is small, around 0.35 sec; moreover residuals don't show any trend with distance. Additionally, using the FD method, we synthesized low frequency, i.e. 0.1-0.5Hz, waveforms for several moderate earthquakes and compared them with the observed waveforms at the strong motion sites. Except for a few limited regions agreement is good and in some cases match is perfect. Therefore we can conclude that the model is acceptable for the simulation of the strong ground motions. Also it can be used as the initial model for farther tuning, using seismic waveforms for example.

## THE EFFECTS OF GEOLOGIC ANISOTROPISM ON THE SEISMIC WAVE PROPAGATION IN ATTENUATION RELATIONSHIP – ID 764

*Y. W. Chang, NationalCenterforResearchonEarthquakeEngineering, Taiwan*
*W. Y. Jean, NationalCenterforResearchonEarthquakeEngineering,*

*Taiwan*
*K. L. Wen, EarthSciencesofNationalCentralUniversity, Taiwan*

The attenuation relationships can be probabilistic descriptions of the ground-motion level to be presented as a function of the earthquake and site parameters. In order to make a good estimate of ground motion, many parameters are taken into consideration in the attenuation relationships. In these attenuation relationships, there is a degree of scatter between the observations and the values calculated by the median attenuation relations. An important issue is to find some measurable parameters or functions that can help to reduce the uncertainty (and/or bias) in the attenuation laws. The island of Taiwan is located in a complex juncture between the Eurasian plate and Philippine Sea plate and in an unstable region between two subduction systems of opposite polarity. The majority of the mountain systems and the main faulting systems are in the north-south direction. Seismic energy dissipation in geologic and tectonic structures is an issue in attenuation relationship. The anisotropism of geology and tectonic structure could affect the attenuation of seismic wave propagation which should be taken into account in the attenuation models of ground-motion. The database from Taiwan networks of RTD and TSMIP is abundant in high quality strong-motion data enough to study the attenuation of wave propagation on geologic structures. These ground-motion data suggest that the wave propagation direction may attributable to the different from geological formation, and tectonic structure. That is a significant effect on the attenuation models of ground-motion. Based on the attenuation relation in Taiwan, the analysis results provide the correction functions which are based on the parameters of wave-propagation direction for the attenuation forms. There the standard deviation of the ground motion prediction model can be significantly reduced. Both the PGA and the spectral acceleration are studied in this paper.

## FROM THE SEISMIC SOURCE TO THE STRUCTURAL RESPONSE: ADVANCED MODELLING BY THE SPECTRAL ELEMENT METHOD – ID 770

*M. Stupazzini, Ludwig-Maximilians-Universitaet, Germany*
*R. Paolucci, Politecnico di Milano, Italy*
*L. Scandella, Politecnico di Milano, Italy*
*M. Vanini, Politecnico di Milano, Italy*

The spectral element method (SEM) is a powerful numerical technique naturally suited for seismic wave propagation and dynamic soil-structure interaction (SSI) analyses. A class of SEM has already been widely used in the seismological field thanks to its capability of providing high accuracy and allowing the implementation of optimized parallel algorithms. We illustrate in this contribution how the SEM can be effectively used also for the numerical analysis of dynamic SSI problems, involving the combined effects of the seismic source, the propagation path, complex geological site conditions, and spatially extended structures as well, such as bridge or tunnels. For this purpose we have made use of the Domain Reduction Method, that we have implemented in SEM, providing some examples of validation.

## GROUND-MOTION ATTENUATION RELATIONSHIPS FOR NEAR-FIELD EARTHQUAKES IN HONG KONG REGION – ID 799

*K. Megawati, The University of Hong Kong, Hong Kong*

Hong Kong is located in South-eastern China, which is a stable continental intraplate region with moderate seismic activity. Although earthquakes have never caused any damage to structures in the modern time of Hong Kong, two notable destructive earthquakes have occurred in the history. The first one was an earthquake occurring in 1874, along a fault near Dangan island, 30 km southeast of Hong Kong. The ground tremors from this near-field earthquake were strongly felt in Hong Kong, with the reported intensity ranging from V to VI on the MMI scale. The second event was an Mw 7.3 far-field earthquake occurring 340 km east-northeast of Hong Kong, in 1918. This earthquake caused the strongest tremors ever felt in Hong Kong, resulting in some damage to masonry buildings. These historical events indicate that both local and distant earthquakes may affect Hong Kong. The likely intensity of ground motions that can be generated by the historical far-field earthquake has been discussed by the author previously. The objective of the present research is to estimate the ground-motion intensities in Hong Kong that can be generated by major near-field earthquakes. The estimation is achieved through a series of ground-motion simulations using a hybrid kinematic-stochastic model. The uncertainties in the rupture process, such as rupture directivity, slip distribution, presence of asperities, rupture velocity and dislocation rise-time, are considered in the simulations. A set of representative attenuation relationships are derived for structural design consideration. The relative importance between these near-field earthquakes ($R < 45$ km) and the far-field ones ($R > 90$ km) is also discussed. The key factors examined are not limited to the peak ground accelerations and velocities, but also include the shape and ordinates of the corresponding response spectra and other special features that may arise from the rupture mechanism of the earthquakes.

## ATTENUATION OF PEAK HORIZONTAL ACCELERATION AND VELOCITY FROM ITALIAN STRONG-MOTION DATA AND COMPARISON WITH PREDICTION EQUATIONS FOR ACTIVE TECTONIC REGIONS – ID 802

*G. Lanzo, University of Rome La Sapienza, Italy*
*G. Scasserra, University of Rome La Sapienza, Italy*
*F. Mollaioli, University of Rome La Sapienza, Italy*
*J. Stewart, University of California Los Angeles, United States*
*P. Bazzurro, AIR Worldwide Corporation, United States*

Probabilistic seismic hazard analyses for Italy are generally performed using empirical attenuation relationships based on local databases of Italian and/or European earthquakes, which are generally shallow crustal events. An alternative is to use attenuation functions derived using the worldwide ground motion inventory for active regions. An ongoing joint research project between Italian and U.S. researchers is investigating whether ground motions recorded in Italy are significantly different from those in other active tectonic regions. In the paper, we will present a database consisting of about 500 accelerograms recorded during 100 Italian earthquakes between 1972 to 2001 with magnitudes between about 4 and 7. This database is unique relative to previous studies using Italian data in that the records have been thoroughly reviewed for data quality (removing S-trigger records, etc.) and uniformly processed by an experienced seismologist using the Pacific Earthquake Engineering Research (PEER) Center standard filtering procedure. Moreover, uniform formats have been developed for describing source characteristics (hypocenter location, strike, dip, rake, and fault plane dimensions) and site characteristics (surface geology, geophysical and geotechnical data, as available). We compile peak ground motion parameters for the records in the database (peak acceleration and velocity). Those data are used with appropriate site, source, and path parameters to investigate magnitude-scaling, distance-scaling, and site effects for peak acceleration and velocity of the Italian data. The results are then compared to magnitude, distance, and site terms from widely used ground motion prediction equations for active regions to investigate whether statistically significant differences are present. The results will provide insight into whether the Italian data exhibits distinct characteristics with respect to the trends observed from active regions elsewhere in the world.

## STRONG GROUND MOTION MODELING FOR THE AUGUST 30, 1986 VRANCEA (ROMANIA) EARTHQUAKE (MW=7.2) – ID 826

*J. Miksat, Geophysical Institute of Karlsruhe University, Germany*
*A. Oth, Geophysical Institute of Karlsruhe University, Germany*
*V. Sokolov, Geophysical Institute of Karlsruhe University, Germany*
*W. Friedemann, Geophysical Institute of Karlsruhe University, Germany*

The intermediate-depth (70-140 km) earthquakes occur-

ring in the Vrancea (Romania) seismogenic zone produce a significant hazard to Romania. Analysis of the macroseismic and instrumental data from the Vrancea earthquakes revealed several peculiarities of earthquake effects: (1) the earthquakes affect very large areas with a predominant NE-SW orientation; (2) the local and regional geological conditions can control the amplitudes of earthquake ground motion to a larger degree than magnitude or distance. The regional earthquake ground motion database is still lacking for records from large events. The numerical modeling of strong motions based on available information can supply the necessary input for seismic hazard analysis. We tested three modeling techniques using, as an example, the large earthquake of Mw=7.2 (30 August, 1986). One of the techniques uses a 2.5D Finite-Difference (FD) method for modeling of wave propagation from source to surface. The technique reveals influence of buried geological structures on ground motion; however the frequency range is limited by 4.5 Hz. The empirical Green's functions method is based on recordings of small events and allows generating acceleration time series within the frequency range 0.5-15 Hz. However, the technique can model ground motions only at sites where enough records of appropriate small earthquakes are available. The third tested method is a stochastic simulation based on empirical models for Fourier amplitude spectra. The method can take into consideration site effects and allows calculations for the whole territory. The disadvantage of the technique is a simplified description of the propagation path effect. The application of these techniques for the case of the August 30, 1986 event allows (1) to examine whether the results of the three modeling techniques are compatible with each other, and (2) to analyze possibilities for developing of hybrid method for accurate prediction of strong ground motions from large earthquakes.

## OVERTURNING MAPS OF A ROCKING RIGID BODY UNDER SCALED STRONG GROUND MOTIONS – ID 861

*L. Sorrentino, Università di Roma "La Sapienza", Italy*
*F. Mollaioli, Università di Roma "La Sapienza", Italy*
*R. Masiani, Università di Roma "La Sapienza", Italy*

The non linear dynamic response to ground motion of a rocking rigid body resting on a plan rigid foundation, representing rocks, archaeological elements, simple architectural components, industrial equipments, on shelf artefacts, has dragged great interest over several decades. Part of such interest is due to the wide scatter in the response and the occurrence of counterintuitive phenomena. E.g. considering one block overturned by a certain signal no overturning was at times observed after scaling up the amplitude, or scaling down the frequency. In this paper is studied the response of a slender rigid rocking block to a set of 20 natural accelerograms, including two pairs of free field and floor recordings. Each recording has both amplitude and duration scaled from 50% to 150% of their actual value. 201 discrete values of amplitude and duration are considered, thus computing 40401 time histories per accelerogram plotted as response maps. As will be highlighted, this can also be interpreted as the response of a set of scaled blocks to an unscaled signal. In each map overturning is marked, as well as, for collapsed blocks, the number of impacts, rocking duration and dissipated energy. The boundary between overturning and no overturning domains prove to be non smooth, non connected and basically fractal like. Moreover, sometimes the depth of such boundary is rather limited, whereas some others is much deeper. An attempt to measure such differences is made, as well as to correlate them with signal characteristics, and to assess which more limited number of non linear analyses is necessary to get, in a statistical sense, the same overturning rate.

## A WAVEFORM INVERSION FOR CHARACTERIZED SOURCE MODELS USING GENETIC ALGORITHM – ID 887

*K. Motoki, Tokyo Institute of Technology, Japan*
*H. Yamanaka, Tokyo Institute of Technology, Japan*
*K. Seo, Tokyo Institute of Technology, Japan*

Strong motions near source regions highly depend on the heterogeneity of the source, and an appropriate procedure to distribute asperities is necessary. A number of source models have been already evaluated in recent a couple of decades since Hartzell and Heaton (1983). But their source models are too complicated to directly apply a model for an estimation of future earthquakes. The information compiled by Somerville et. al. (1999) are referred to make a source model as inner source parameters. But the criteria are not based on physical manner and not always to produce an optimal solution. The purpose of this study is to evaluate directly a characterized source model, which is composed of asperities and background region and useful for a prediction of earthquake motions, with observed waveforms using genetic algorithms. This method produces simple models and the number of unknown parameters of this method is less than the conventional method, but this model cannot solve as a linear problem. Each unknown parameter is transformed to binary and allocated to a variable gene. Before applying observed data, we conducted a numerical test. This method is useful only less for 2 asperities, because the calculation for more than 3 asperities costs enormous time. 2 solutions can be considered against this problem. One is a procedure adding asperities one by one, and another one is a procedure increasing resolution gradually. The latter has a defect to fall into local minimum. Therefore, we adopt a former procedure, and applied in the case of the 1995 Kobe earthquake. The solved source model successfully reproduces the observed ground motions, and it is similar to the models evaluated in previous researches.

## STRONG GROUND MOTION MODELING FOR THE 2004 FIROOZABAD-KOJOOR EARTHQUAKE, NORTH OF IRAN – ID 895

*A. Golara, International earthquake engineering &seismolo, Iran (Islamic Republic Of)*
*H. Hamzehloo, International earthquake engineering &seismolo, Iran (Islamic Republic Of)*

An earthquake with estimated magnitude of 6.3 has occurred in the North of Tehran on May 28, 2004 2:38:46 GMT. The causative fault for this earthquake wasn't known exactly base on surface geological observations. Therefore, we tried to model the rupture process by considering Kojoor fault and North Alborz fault in this area. We: 1) have studied the strong ground motion data, which recorded by Building House Research Center strong ground motion network. 2) have used M<5.0 aftershocks that occurred throughout the area and not necessarily along the fault to be modeled. 3) have simulated strong-ground-motion using empirical green function method. For this, we generated 30 models for each of these faults. It is observed based on comparison between observed and simulated records that the Kojoor fault was the causative fault for this earthquake. The comparisons were based on the ground motion parameters such as peak ground acceleration, acceleration root mean square, duration, Fourier spectra and pseudo-acceleration spectra in all stations and for the three components. It was identified that the "best fitting" rupture models occurred in the vicinity of 36.29oN 51.602oE with center of rupture near 19 km with unilateral rupture towards North-West.

## MODELING DIRECTIVITY OF STRONG GROUND MOTIONS WITH A KINEMATIC FRACTAL SOURCE MODEL – ID 916

*J. Ruiz, IRSN, France*
*D. Baumont, IRSN, France*
*P. Bernard, IPGP, France*
*C. Berge-Thierry, IRSN, France*

We present an alternative kinematic fractal source model able to simulate broadband accelerograms with spectral amplitudes proportional to a fraction of the directivity coefficient Cd in the far-field approximation. Our approach is based on a composite source description where sub-events are generated using a fractal distribution of sizes. Each elementary source is described as a crack-type slip model growing radially from a nucleation point when the rupture front reaches it. In order to better control

the directivity effect, the location of the nucleation point for an elementary source is assumed to be scale-dependent. For the larger sources, the nucleation point is located near the intercept of the crack with the rupture front, whereas for smaller sources, it is randomly chosen within the crack. For simplicity, we assumed a constant rupture velocity. Each sub-event is set up with a size dependent rise-time, assuming a boxcar source time function. The slip velocity is computed at each fault mesh by adding the source time function of the sources contributing to slip at this location. The resulting mean slip velocity functions are very similar to the ones derived from dynamic modeling. Ground motion synthetics are computed by convolving the slip velocity functions with the Green functions. We show that, in the far-field approximation, accelerogram spectra follow the w2 model with amplitudes controlled by the frequency-dependent directivity effects. In particular, spectral amplitudes at high-frequencies are proportional to a fraction of Cd. We are now attempting to confront statistically these modeling with the spectral amplitudes of the accelerograms compiled in database.

## TORSIONAL GROUND MOTION FEATURES USING DENSE ARRAY DATA – ID 972

*G. R. Nouri, IIEES, Iran (Islamic Republic Of)*
*M. R. Ghayamghamian, IIEES, Iran (Islamic Republic Of)*
*R. Foroozan, IIEES, Iran (Islamic Republic Of)*

There are studies available on the response of structures due to torsional component of ground motion. The majority of them are focused on analytical solutions based on simplified assumptions for the torsional ground motion and they do not employ the data obtained from real events because of the difficulty in evaluation of the torsional component. Since the conventional instruments are designed to record the translational motions, the torsional component is indirectly estimated from the translational ones. The array observation is a robust tool for this aim. In this paper, the data from Chiba dense array, located 30km east of Tokyo, are analyzed to investigate the properties of the torsional component of ground motion. This array has been operational since 1982 and consists of accelerometers spaced in the range of 5 to 300 meters from each other. Chiba array has recorded a considerable amount of data from many earthquakes with different specifications. This provides a unique opportunity to perform a comprehensive study on the characteristics of torsional ground motion and their variations with the seismological parameters. Since the increase of distance between the stations generally causes the coherency to be decreased, the torsional component can reliably estimated using the data from an array of very close spacing. Furthermore, due to higher coherency values, the characteristics of the torsional motion can be examined in a broader frequency band. It is seen that the response spectra of torsional and translational components are not proportional to each other and their relation is dependent on the earthquake magnitude and the distance between the accelerometers.

## DAMAGE POTENTIAL OF THE SEISMIC STRONG MOTION – ID 1022

*M. Kostov, CLSMEE, Bulgaria*
*N. Koleva, CLSMEE, Bulgaria*

The presented paper shows some of the recent results for correlation of comulative absolute velosity (CAV) with the macroseismic intensity, magnitude and distance (attenuation functions). The analyses are based mainly on European strong motion data. The processing is performed separately for intermediate depth earthquakes (Vrancea seismic region), regional shallow earthquakes and moderate local earthquakes. The results show that CAV correlates with the intensity, magnitude and distance in similar way as the peak values of strong motion. There is significant difference of expected CAV from local earthquakes and from strong regional seismic excitations. The local earthquakes although producing high accelerations are developing very small CAV and respectively small damage potential. The analyses show that intermediate depth earthquakes may produce significant CAV on very large distances, i.e. may affect large territories and produce damage

## ANN - BASED ATTENUATION RELATIONSHIP FOR ESTIMATION OF PGA USING INDIAN STRONG - MOTION DATA – ID 1132

*J. Pathak, Jorhat Engineering Collage, India*
*P. Dilip, IIT, Roorkee, India*
*P. N. Godbole, IIT, Roorkee, India*

The estimation of expected ground motion in terms of peak ground acceleration (PGA), peak ground velocity (PGV) and 5% damped spectral acceleration (SA) are fundamental inputs to earthquake hazard assessment at a specific site. An Artificial Neural Network (ANN) based model is developed to predict horizontal peak ground acceleration using data from strong-motion arrays in India for eight earthquakes. ANN model is a cognitive model, which is trained on data to make prediction and eliminates the priori assumption regarding the form of the model. The knowledge about the attenuation is embedded in the form of weights of the network connections, which can be recalled for future prediction on novel data. The significant association of the additional data are learnt directly by training on presented data set and re-development of rigorous mathematical expression for representing such associations are not required. A new heuristic approach to train and test various possible networks is presented. A detailed parametric study was carried out to find the optimum configuration of the networks in three phases of training. Performance test was done on the residual error by analyzing their correlation with distance. A single model was able to learn the difference in attenuation rate in different regional setting of central Himalayan and North-East India region reasonably well and gave consistently better prediction than the various existing empirical attenuation relations for eight Indian earthquakes. The ANN based model shows better agreement of the predicted peak ground acceleration with the recorded peak ground acceleration compared to the predictions made by empirical attenuation relationships used in India. The ANN based approach for prediction of PGA provides an alternative method for developing attenuation model in various region of the world by systematically utilizing the large data base recorded all over the world.

## SPECTRAL VARIATIONS OF THE SPECIFIC BARRIER MODEL FROM VARIOUS ISOCHRON AND SUBEVENT DISTRIBUTIONS – ID 1137

*B. Halldorsson, Earthquake Engineering Research Centre, Iceland*
*A. Papageorgiou, University of Patras, Greece*

The Specific Barrier Model (SBM) is a particular case of a composite seismic source model according to which the seismic moment is distributed in a deterministic manner on the fault plane on the basis of moment and area constraints. Namely, in formulating the model it is assumed that a rectangular fault surface is composed of an aggregate of subevents of equal diameter, the "barrier interval". Furthermore, the subevents are assumed to rupture randomly and statistically independent of one another as the rupture front sweeps the fault plane. The seismic radiation received by a recording station at a site depends on the location of the station relative to the fault plane, the location of rupture initiation (hypocenter) and onset times of the rupturing subevents. All the above factors are neatly taken into account by the isochrons. Furthermore, the seismic radiation is also affected by the basic assumption of equal-size subevents of the SBM. We therefore investigate the sensitivity of the far-field spectra of the SBM to the following two factors: (1) The distribution of the isochron curves on the fault plane, and (2) the size-distributions of the subevents. We quantify the effects and derive closed form expressions of the far-field source spectra. The effects of the former factor are manifested mainly at the intermediate frequencies while the latter factor affects primarily the amplitude of the plateau of the high frequency radiation of acceleration spectra. It turns out that the spectral amplitude of the high frequency plateau of the spectra corresponding to different size-distributions does not differ significantly from that of the SBM (i.e., constant size subevents) for constant local stress drop. We conclude that, despite its simplifying assumptions, the SBM appears to be the most simple, yet effective,

way to capture the essential characteristics of a composite seismic source.

### ICEARRAY: A NEW SMALL-APERTURE STRONG MOTION ARRAY IN THE SOUTH ICELAND SEISMIC ZONE – ID 1138

*B. Halldorsson, Earthquake Engineering Research Centre, Iceland*
*R. Sigbjornsson, Earthquake Engineering Research Centre, Iceland*

The tectonically unique and populated South Iceland Seismic Zone (SISZ) has been the location of numerous large destructive earthquakes in the past. Its capability to produce earthquakes that may exceed magnitude 7.0 is a constant threat to lifelines, such as pipelines, electric transmission systems, dams and bridges, in the region. In terms of earthquake safety the spatial variability of earthquake ground motions, although often neglected in design considerations, is of particular importance to such extended structures because it can have dramatic effects on their earthquake response and cause damage. In order to reliably estimate such effects, spatial variability models must be developed from data recorded on a dense seismograph array in the region. For that reason it is proposed to establish the ICEARRAY network, a new small-aperture strong motion array of broad-band, wide dynamic-range accelerographs in the SISZ. The regional spatial variability models developed from data recorded on the array will enable the first reliable assessment of such effects on lifeline structures from large scenario earthquakes in the SISZ. For the comprehensive near-fault and far-field simulation of strong motions, earthquake sources are represented in terms of the Specific Barrier Model (SBM), which provides the most physically realistic, yet parsimonious, description of fault rupture. The spatial variability models, along with the novel development of the SBM in the context of a hybrid simulation technique will thus produce physically realistic and self-consistent, broad-band simulations of spatially variable strong ground motions. The developed models and techniques will be easily transferable to application in other regions in Europe due to the quantitative regional comparison of earthquake source scaling and medium characteristics made possible with the comprehensive approach taken in this study, which forms a new bridge between seismology and lifeline earthquake engineering.

### ATTENUATION IN ICELAND COMPARED WITH OTHER REGIONS – ID 1157

*S. Ólafsson, University of Iceland, Iceland*
*R. Sigbjornsson, University of Iceland, Iceland*

The steadily growing number of recorded accelerograms from various regions of the world, as well as increased accessability, have led to improvements in estimates of paremeters in ground motion equations. This has resulted in more awerness of possible regional differences and better estimates of seismic-hazard. The main objective of this work is to compare strong-motion estimation models found in the litterature. Peak ground acceleration data obtained from databases for different regions are used to assess the representativeness of the models in terms of validity and reliability. The earthquakes used in the study are grouped according to source mechanism, source depth, tectonic environments and site conditions. Data from shallow, strike slip-slip earthquakes, recorded on stiff soil are used as a benchmark for the comparison. A theoretical ground motion estimation model is also outlined in some details and than used in the comparison. Both horizontal and vertical components of acceleration are considered. Special consideration is given to near source data. Data outside 100 km radius is not included in the study. When comparing peak ground acceleration (pga) data from earthquakes with similar magnitudes, source mechanism and crustal depth it is observed that the data from Europe and North-America have higher pga levels than observed in Iceland corresponding to a factor of approximately 1.4. This confims earlier studies of the acceleration data from Iceland. The possible reasons for this difference are examined. The conclusion is that the difference in acceleration levels can be attributed to dissimilar tectonic environments.

### PROPOSAL OF A SYSTEM OF SPECTRUM INTENSITY SCALES FOR THE SCALING OF NATURAL ACCELEROGRAMS ACCOUNTING FOR HYSTERETIC BEHAVIOUR AND LOCAL SITE CONDITIONS. A NEW SYSTEM AND ITS APPLICATION ON DISPLACEMENT-BASED DESIGN – ID 1196

*J. E. Martinez-Rueda, University of Brighton, UK*

Past studies have revealed a good correlation between spectrum intensity (SI) and ductility demand. Accordingly, SI can be used as an objective measure of instrumental intensity for earthquake ground motion as efficient earthquake-resistant structures are expected to behave inelastically under the design earthquake. The present paper proposes a system of spectrum intensity scales of optimum correlation with ductility demand. The system is based on an extensive parametric study on the inelastic seismic response of SDOF systems under the action of a world-wide ensemble of natural accelerograms of strong ground motion. Parameters accounted for include the type of hysteretic response (with stiffness degradation vs. without stiffness degradation), initial stiffness of the structure (as a function of yield period), the yield strength of the structure (as a function of the yield seismic coefficient) and the local site conditions (considering separately natural accelerograms for rock, stiff soil and soft soil). The combination of the above parameters resulted in 45,000 nonlinear time-history analyses, which are interpreted initially in terms of the degree of correlation between displacement ductility demand and the spectrum intensity of the seismic input. The main results of this study include the proposal of a system of spectrum intensity scales recommended for earthquake scaling, as well as, a semiempirical model to estimate ductility demand as a function of spectrum intensity, type of hysteretic response and local site conditions. It is proposed that this semiempirical model leads to an alternative way of conducting displacement-based design.

### SIMPLIFIED ANALYTICAL MODEL OF EARTHQUAKE RESPONSE SPECTRA FOR STRIKE-SLIP EARTHQUAKES – ID 1212

*J. Snæbjornsson, University of Icelan, Iceland*
*S. Olafsson, University of Iceland, Iceland*
*R. Sigbjornsson, University of Iceland, Iceland*

The objective of this paper is to develop an analytical simplified model that directly relates response spectral ordinates to the site, path and source parameters. The paper describes the modelling of earthquake response spectra for shallow strike slip earthquakes in the near- and far-field and assesses the statistical significance of its fitting to strong motion data. The data set applied includes strong motion records from two magnitude $6\frac{1}{2}$ events that occurred in the South-Iceland seismic zone in June 2000. Those events provided us with a data set consisting of roughly 47 records obtained in the two earthquakes, with epicentral distances between 5 and 150 km and hypocentral depth less than 10 km. The model of the sdof response spectrum is derived in a closed form based on the Brune spectra for the near- and the far-field, modelling the high frequency tail in both cases by an exponential function. The closed form solution is found to be advantageous in studies on structural reliability and risk. The main results are that the derived models fits the data fairly well providing residuals comparable to the residuals of models obtained by the widely used regression analysis. Furthermore, the response spectra attenuate with increasing distance more rapidly than R-1 where R is the distance to causative fault. The model based on the Brune theory is found to be adequate from an engineering point of view for many applications. It is also considerably more straightforward to apply than models based on the Haskel-Savage theory, although they may give a better fit to the response data, especially in the high frequency range of the response spectrum.

## A HYBRID METHOD FOR SIMULATING STRONG GROUND MOTION RECORDS – ID 1265

*E. Ismael, Institute of Engineering, UNAM, Mexico*
*L. Esteva, Institute of Engineering, UNAM, Mexico*

In order to have a good characterization of the seismic risk for reliability structural analysis we need an approach that allows us to represent the seismic intensity at a given site. The lack of actual records is a limitation that we have, therefore it is necessary to simulate seismic records specially those for large magnitudes. There are several techniques for getting synthetic records. One of them is the generalized attenuation functions developed by Alamilla et al (2001) and the other is the empirical Green's functions by Ordaz et al (1995). Unfortunately these methods have some limitations to be used for reliability analysis. For example in the Green's functions method the uncertainty related to the magnitude and distance of the event is not considered, and in the generalized attenuation functions the site effects and features of trajectory are not taken into account. Such information is important in order to get the nearest characterization of the seismic risk at a site.

To overcome these limitations we propose here a hybrid method that takes advantage of the above approaches. First we consider all the available information in order to get a good characterization of seismic intensity. Then with the actual data we develop functions that describe the amplitude, frequency, effective duration and the spectral density whose parameters are determined in terms of the magnitude and distance. These functions are calculated for a given site. The above information is used to generate by simulation a small record (Green's function) given the magnitude and distance of interest, after that we can use the empirical Green's function method in order to obtain synthetic accelerograms. The method is illustrated through an example for a site located at a soft soil in the Valley of Mexico.

## COMPUTATION OF SYNTHETIC SEISMOGRAMS OF SOME SIGNIFICANT EGYPTIAN EARTHQUAKES USING THE REFLECTIVITY METHOD – ID 1284

*S. Salah El-Hadidy Youssef, National research Institute of Astronomy and Geoph, Egypt*

The reflectivity method is one of the major methods for the computation of theoretical seismograms. The reflectivity method for the computation of synthetic seismograms, as devised by Fuchs and Muller, is extended to include the elastic transmission losses and time shifts due to a stack of layers on top of the reflecting medium. The program REFSEIS.F by Joachim Ungerer and modified by E. Vielandt generates complete (body and surface wave) synthetic near-and far field seismograms for a generalized point source of Brustle-Muller model or an impulse excitation which is located within horizontal layered medium. REFSEIS.F calculates either displacement or velocity or acceleration. The source excitation function is implemented in the first part of the program, and may be changed. Seismograms are represented in a cylindrical coordinate system with origin at the epicenter as three components. The source mechanism and its orientation are described by the Cartesian components of the source moment tensor. Synthetic seismograms of some significant Egyptian earthquakes that have been occurred in some specific seismogenic zones have been calculated using REFSEIS.F software. The source parameters and back azimuth of the selected events were calculated. The focal mechanism solutions of these events were calculated and the fault parameters are used to calculate the six moment tensor components. The proper crustal model including velocities of P and S –waves, density and quality factors of P and S –waves, is used to calculate the synthetic seismogram for each event. The calculated synthetic seismogram is compared with the observed ones. After getting a good fitting between observed and synthetic ones, the simulated strong ground motion data is calculated for the maximum expected earthquake for each seismogenic zone at different specific sites.

## IDENTIFICATION OF SEISMIC WAVE FIELDS BY PATTERNS IN TIME-DEPENDENT PRINCIPAL CORRELATION AXES – ID 1288

*J. Bretschneider, TU Dresden, Germany*
*R. J. Scherer, TU Dresden, Germany*

Adequate stochastic seismic load models should be based on wave fields, as the non-stationarity of strong ground motion is caused by invariant characteristics of wave types, expressed by stable patterns in the course of the 3D principal direction of acceleration. These patterns are generated by specific particle dy-namics and sequence of wave fields, while their duration, form and intensity are ambiguously influenced by source, path and site effects. The focus is to find patterns which clearly identify wave fields significant for structural response and can be utilized to analyse and model these wave fields as non-stationary mod-ules. Especially, fast single-record indicators are sought for surface waves, which carry heavy risk mostly due to their long duration and narrow spectrum in the response range of buildings and are not properly addressed in current building design regulations. In measurements, general patterns are obvious but not very pronounced as the wave fields are distributed over components and strongly overlap. In order to receive stable patterns, the method of time-dependent principal correlation axes is applied and refined, which is able to separate and identify wave fields based on particle dynamics and variance classi-fication. For interpretation of the patterns, a comparative model of the excitation process is set up which is iteratively refined, starting with a unidirectional one-phased rupture and normal site amplification which leads to two direct and one indirect model wave fields. The related 1D-model patterns are formulated in a general way using parametric shape functions which will be fit to empirical data. Associated patterns in corresponding indicators are significant. The extension of the comparative model to more complex rup-ture, regional and local wave generating features leads to stepwise refined patterns. Agreement criteria with the data model are formulated with respect to load relevance terms.

## STANDING WAVES AND MACROSEISMIC FIELD: EMPIRICAL AND THEORETICAL EVIDENCES – ID 1289

*F. Aptikaev, Institute of Physics of the Earth, RAS, Russian Federation*
*O. Erteleva, Institute of Physics of the Earth, RAS, Russian Federation*

The data on abnormal fluctuation of macroseismic field was collected. For example, during the Gobi-Altai Earthquake 1957, Ms = 8.5, Io = 12.0, were observed decreasing of seismic intensity down to 5-5.5 at the distances 20.0, 25.0 and 27.5 km. Then on distances about 55 km intensity grows up to I = 11-12. Next line of reduced intensity is observed on distances about 75 km from rupture line on earth surface. Similar data are obtained in different countries by macroseismic and instrumental observations. Because of these phenomena can not be explained by ground condition, influence of standing waves is supposed. The best results are obtained when shortest distances from rupture surface are used. In the zone of amplification intensity can be even larger than in the epicenter. There is a rhythmic alternate of knot and loop zones in epicentral area. When two nearest knot zones and two loop ones are processed together, one can obtain

lgR = 0.33Ms–1.40+lg n+-0.15, where R is the distance to loop or knot, n is equal to 1, 2, 3, 4; even numbers correspond to loops and odd ones – to knots.

Obtained results are in good agreement with theory. Common solution of wave equation for simplest case is

A(t,R)=sin[(t+R/v)360/T] + sin [(t-R/v)360/T], where R is distance, v – velocity of wave propagation, t is time.

This sum describes standing waves. It is easy obtain the position of knots and loops along axis R:

R = nl/2,where l is wave length; even numbers n correspond to loops and odd ones – to knots.

### STOCHASTIC SIMULATION OF EARTHQUAKE GROUND MOTIONS ACCOUNTING FOR BASIN-EDGE GENERATED SURFACE WAVES – ID 1368

*B. Halldorsson, University of Iceland, Iceland*
*A. Papageorgiou, University of Patras, Greece*

The Specific Barrier Model has recently been calibrated to earthquakes of different tectonic regions, and successfully applied in modeling earthquake strong ground motions. The method that we adopted in synthesizing strong ground motion is referred to in the literature as the "Stochastic Approach". The way this approach has been implemented by almost all investigators does not account for the "basin-edge generated surface waves". These waves are generated by diffraction of incoming seismic radiation at the edges of sedimentary basins. Such waves are usually a distinctive feature of the motions recorded at sites inside basins. They enhance the spectral amplitudes of the long periods ( 2 to 3 sec and longer) and they prolong the duration of motion. We expand the capabilities of the Stochastic Approach to account for basin-edge generated surface waves. The database that we use to calibrate our method consists of ground motions recorded at stations located in the Los Angeles (LA) Basin. These motions were generated by earthquake events that occurred outside the LA Basin (1952 Kern County, 1971 San Fernando, 1992 Landers, and 1994 Northridge, earthquakes). We consider also the motions of the 1979 Imperial Valley earthquake. The latter were generated by an earthquake fault inside a basin. The simulation technique that we use is based on the physics of surface wave propagation and thus accounts for dispersion. This in turn renders the simulated time-series non-stationary (evolutionary) with respect to their frequency content. Finally, we explore how our physically based technique relates to other phenomenological simulation techniques of non-stationary processes proposed by engineers.

### MODELLING DIRECTIVITY EFFECTS OF THE OCTOBER 31, 2002 (MW=5.7), MOLISE, SOUTHERN ITALY, EARTHQUAKE. – ID 1424

*G. Franceschina, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*F. Pacor, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*G. Cultrera, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Emolo, Università degli Studi "Federico II", Italy*
*F. Gallovic, Charles University, Czech Republic*

Acceleration time series recorded by the Italian Strong Motion Network (RAN) during the October 31, 2002 (Mw=5.7), Molise earthquake, are employed in order to investigate source effects on the ground motion in the epicentral area. We consider two different seismogenic sources: a fault model inferred from inversion of teleseismic, regional and local seismic signals (Vallée and Di Luccio, 2005), and a fault model based on seismotectonic data (Vannoli and Basili, 2005, personal communication). Both source studies suggest a deep location of the earthquake fault plane (ranging from 6.0 to 20.1 km and from 12.0 to 19.9 km, respectively), however, with considerably different fault lengths (5.2 and 10.5 km, respectively), and widths (14.2 and 8 km, respectively). Due to these differences, only the second model allows for effective horizontal unilateral rupture propagation. Finite fault effects are modelled by the Deterministic-Stochastic Method (DSM) of Pacor et al.(2005), assuming a k-square model for the slip distributions on the faults. We simulate the October 31, 2002 earthquake considering: 1) Vallée and Di Luccio (2005) fault with a bilateral rupture propagation, and 2) Vannoli and Basili (2005) fault with both bilateral and unilateral directions of the rupture propagation. The spectral attenuation is modelled using a regional estimate of the quality factor (Castro et al.,2004) and k values estimated from acceleration records. Comparison between synthetic and recorded data at nearby stations (epicentral distances less then 50 km) suggests that a unilateral rupture propagation explains better the observed ground shaking in terms of frequency content and peak ground motion. Assuming the source model with unilateral rupture propagation, we utilize both asymptotic and full wave field methods in order to simulate ground shaking for several slip scenarios at a regular grid extending up to 100 km epicentral distance. These results are then subjected to comparison with peak ground accelerations recorded in the far field.

### A ROBUST METHOD TO OBTAIN THE AMPLITUDE MODULATION FUNCTION OF A STRONG MOTION RECORD – ID 1445

*C. R. Sánchez-Carratalá, Technical University of Valencia, Spain*
*I. Ferrer, Technical University of Valencia, Spain*

Assuming that an earthquake is adequately represented as a uniformly modulated non-stationary random process, an amplitude modulation or intensity function that models the evolution of the energy content over time can be defined. In this paper a robust method to fit a prescribed theoretical amplitude modulation function to a strong motion record is presented. Taking into account the non-stationary nature of real earthquakes, it is evident that the exact intensity function cannot be obtained from a single record, as the process is not ergodic. Instead of it, the common practical approach consists of searching a rather smooth function that is at least capable of describing the most important features of the record in relation to the energy content evolution.

The intensity function of a uniformly modulated non-stationary random process can be shown to be a normalized version of the standard deviation function of the process. In the limiting case of a non-stationary process with time independent averages (i.e., a stationary process), the intensity function becomes a constant. It is shown here that the value of this constant can be directly calculated from the earthquake record by a least square procedure if the standard deviation of the underlying stationary process is set equal to unity. Extending this property to the general case of a uniformly modulated non-stationary process, it is suggested that a nonlinear least square procedure could also be used to fit a prescribed deterministic intensity function to a strong motion record. The way to check the goodness of the fitting is based on calculating the corresponding underlying stationary signal and then verifying its stationarity. An error parameter is proposed to assess the fitting and to compare the results obtained with different intensity functions. Finally, the method is applied to some recent earthquakes using different theoretical amplitude modulation functions.

### SIMULATION OF EARTHQUAKE ACCELEROGRAMS USING WAVELET S – ID 1555

*A. Arash Zandieh, University of Tehran, Iran (Islamic Republic Of)*

In dynamic analysis of structures it is necessary to use accelerograms. Accelerograms are also needed for laboratory simulations. This paper describes a procedure that utilize the wavelet packet decomposition of recorded accelerograms and relate the evaluated coefficients to energy input in different frequency bands. These energy input time histories are related by neural networks to physical parameters of earthquake ground motion: moment magnitude (Mw), closest distance to fault rupture (R) and soil condition (S). Furthermore, a procedure to simulate earthquake ground accelerations by wavelet packet inverse transform is developed which perseveres the target time-frequency characteristics of existing ground motion records. The goodness of simulation procedure are evaluated by several tests the result is quite remarkable.

### NUMERICAL SIMULATIONS OF THE GROUND DAMAGES AT GERACE DURING THE CALABRIAN SEISMIC EVENTS IN 1783 – ID 1568

*A. Costanzo, University of Calabria, Italy*
*F. Silvestri, University of Calabria, Italy*

Gerace is located on a cliff (about 480m a.s.l.), characterized by continuous erosion processes affecting the slope instability of the valley borders. The upper part of the cliff of Gerace is formed by a slab constituted, in sequence, by calcarenites (with thickness of 70m), clayey marls (90m), sand (30m). This slab floats

on a thick layer of varicoloured clay (more then 200m). Since 5 February up to 28 March 1783 five strong earthquakes occurred in Calabria. During such seismic sequence, Gerace represented an anomaly; while the seismic epicentres shifted northwards, the site showed ground damages. For each event, the distribution of macroseismic intensity and environmental damages permitted to ascribe the generation of the main events to different seismogenic zones, showing interactions among them. Different assumptions were formulated in literature on the source location for the first earthquake, attributed either to Cittanova or to GioiaTauro Faults. The latter uncertainty induced the authors to compare the two hypotheses assuming both a 'macroseismic' and a 'seismogenic' approach; on the basis of the ground motion parameters, estimated according to different attenuation laws, seismic records were selected and synthetic accelerograms generated as input motions. The seismic response of the vertical along the town centre was simulated by one-dimensional and two-dimensional analyses. The results of 1D analyses permitted to assess the results obtained by the different calculation methods, whereas the comparison between 1D and 2D modelling showed the effects of the impedance contrast between clay and calcarenites combined with the topography ones. The shear strains generated by the earthquakes within the clay deposit trespassed the volumetric threshold strain, inducing a pore pressure buildup which dissipated very slowly. These results have then justified the occurrence of accumulated large deformations due to sliding, following the whole seismic sequence, reported by the chronicles.

## GROUND MOTION ATTENUATION, EXTREMES AND PERCEPTIBILITY HAZARD OF ACCELERATION, VELOCITY AND MACROSEISMIC INTENSITY IN BULGARIA AND THE BROAD BALKAN REGION – ID 1661

*J. Bayliss, University of East Anglia, UK*
*P. Burton, University of East Anglia, UK*

Knowledge of ground motions resulting from large earthquakes constitutes a primary concern for modern engineering seismology, due to their potentially destructive effects on urban centres and infrastructures. Knowing characteristics of peak accelerations, velocities and macroseismic intensities a site may experience enables engineers to confidently design structures to withstand such extreme earthquake loadings.

For Bulgaria and its surrounding area (as well as key urban areas within the region), a ground motion hazard assessment has been undertaken using a new earthquake catalogue. Selected ground acceleration and velocity attenuation relations have been applied in combination with Gumbel's first asymptotic extreme distribution, to obtain estimates for peak ground accelerations and velocities. These forecasts are associated to return periods of 50, 100 and 200 years (notionally A50, A100, A200 and V50, V100, V200) and are maximums expected in the time interval specified.

Analysis is extended by applying relations for macroseismic intensity attenuation and epicentral intensity to develop the concept of earthquake perceptibility in terms of intensity, ground acceleration and velocity. That is, the probability a site perceives ground shaking of at least ground motion parameter X arising from an earthquake of magnitude M. Estimates for the most perceptible earthquake magnitudes at intensities VI, VII and VIII, ground accelerations of 0.2g, 0.3g and 0.4g and ground velocities of 10cm/s, 20cm/s and 30cm/s are also obtained.

The results for ground motion and perceptibility forecasts are contoured using a 'moving cell' approach across the full region with cells placed at half degree intervals of latitude and longitude. Conditions forecast estimates for the capital, Sofia, of A50=61cm/s/s and 85cm/s/s (with/without depth control respectively). Magnitude perceptibility estimates are M(A=0.2g)=6.08, M(A=0.3g)=6.32, M(A=0.4g)=6.56.

## PREDICTIVE RELATIONSHIP FOR PEAK GROUND DISPLACEMENT FOR EUROPE: ARTIFICIAL NEURAL NETWORK APPROACH – ID 1676

*A. Irshad, NWFP UET, Pakistan*
*M. H. El Naggar, University of Western Ontario, Canada*
*N. Akhtar, NWFP UET, Pakistan*

The predictive relationships for Peak ground displacement (PGD) are far less common than those for peak ground acceleration (PGA) and peak ground velocity (PGV). Quite few relationships are developed for PGD based on European earthquakes which carry quite huge standard deviations for the simplistic attenuation models considered in their development. In this study a predictive relationship for PGD is developed based on 358 records from 42 European earthquakes processed by J.J. Bommer using Artificial Neural Network. The surface magnitude (Ms), distance of site from surface projection of the rupture (R), and the broad categories of soil type (soft soil, stiff soil, and rock formation) are the three input parameters. The Ms ranges from 5.5 to 7.9, and R ranges from 3 Km to 260 Km. The technique used for function mapping is the Feed forward Levenberg-Marquardt back propagation algorithm. 75% of the total data (268 earthquake records) are used to train the model, while remaining 25% of the total data (90 earthquake records) are used to test the performance of the trained neural network. The attenuation curves are compared with the Bommer J. (2002). The standard deviations both for training and testing data are comparatively lower i.e. 26.6%.

## EFFECTS OF VERTICAL COMPONENT OF NEAR FAULT GROUND MOTIONS ON SEISMIC RESPONSE OF HIGHWAY BRIDGES – ID 1677

*Z. Yilmaz, University of California Davis, United States*
*E. Erduran, University of California Davis, United States*
*S. Kunnath, University of California Davis, United States*
*R. Chai, UNIVERSITY OF CALIFORNIA DAVIS, United States*
*N. Abrahamson, University of California Davis, United States*

Typically, vertical component of the ground motion is not considered properly in seismic design, but in some cases the vertical component can have a significant effect on structural response. A systematic study to investigate the effects of vertical acceleration on the overall response of typical highway bridges is underway. The objective of this study is to determine what conditions lead to the vertical component having a significant effect on the horizontal response of bridge columns. The cases for which vertical component had a significant effect on the horizontal response cannot be predetermined from simple characteristics of the vertical ground motion such as response spectral values or peak ground motion values. Detailed phasing of vertical and horizontal time series are assessed to determine what conditions cause the observed large differences of structural responses with and without the vertical component. Nonlinear simulation models of existing bridges designed to CALTRANS specifications are subjected to ground motions selected from the PEER_NGA database. The simulations are carried out in two stages: at first, only horizontal components of the motion will be applied; while in the second stage both horizontal and vertical components will be applied simultaneously. Important response measures will be monitored to gain an insight into the effects of vertical acceleration on the inelastic response of the bridge structures. Analytical simulations will provide a basis for investigating features of the ground motion that most significantly contribute to adverse effects from vertical accelerations. Continuing studies will address how often these conditions happen during earthquakes for use in hazard analyses. This will allow designers to determine when they need to include a vertical component in their structural analyses. Findings from the study will provide the basis for developing revised guidelines to address vertical ground motion effects in the seismic design of highway bridges.

## VRANCEA SEISMIC SOURCE CALIBRATION USING A SMALL-APERTURE ARRAY – ID 1712

*E. Popescu, National Institute for Earth Physics, Romania*
*M. Popa, National Institute for Earth Physics, Romania*
*A. O. Placinta, National Institute for Earth Physics, Romania*
*I. A. Moldovan, National Institute for Earth Physics, Romania*
*M. Radulian, National Institute for Earth Physics, Romania*

A small-aperture seismic array (BURAR) was installed in 1999 in the northern part of the Romanian territory (Bucovina area). Since then, the array has been in operation under a joint cooperation programme between Romania and USA. The array consists of 10 stations installed in boreholes (nine short period instruments and one broadband instrument) with enough high sensitivity to properly detect earthquakes generated in Vrancea subcrustal domain (at about 250 km epicentral distance) with magnitude Mw above 3. Our main purpose is to investigate and calibrate the source parameters of the Vrancea intermediate-depth earthquakes using specific array techniques and data provided by BURAR. Fifty earthquakes with magnitudes between 2.9 and 6.0 were selected, including the recent events of September 27, 2004 (45.70oN, 26.45oE, h = 166 km, Mw = 4.7), October 27, 2004 (45.84oN, 26.63oE, h = 105 km, Mw = 6.0) , May 14, 2005 (45.66oN, 26.52oE, h = 146 km, Mw = 5.1), June 18, 2005 (45.69oN, 26.69oE, h = 149 km, Mw = 4.8), and December 13, 2005 (45.72oN, 26.65oE, h = 144 km, Mw = 5.1), which are the best ever recorded earthquakes on the Romanian territory. Empirical Green's function deconvolution and spectral ratio methods are applied for pairs of collocated events with similar focal mechanism. Stability tests are performed for the retrieved source time function using the array elements. Empirical scaling and calibration relationships are also determined. Our study shows the capability of the BURAR array to determine the source parameters of the Vrancea intermediate-depth earthquakes as a stand alone station and demonstrates that the recordings of this array provides reliable and useful tools to efficiently constrain the source parameters and consequently source scaling properties.

## HIGH-FREQUENCY SPECTRAL SHAPE OF ACCELERATION DATA RECORDED IN CASE OF VRANCEA (ROMANIA) INTERMEDIATE-DEPTH EARTHQUAKES – ID 1713

*M. Radulian, National Institute for Earth Physics, Romania*
*E. Popescu, National Institute for Earth Physics, Romania*
*A. O. Placinta, National Institute for Earth Physics, Romania*
*M. Popa, National Institute for Earth Physics, Romania*
*I. A. Moldovan, National Institute for Earth Physics, Romania*
*B. Grecu, National Institute for Earth Physics, Romania*

A set of 150 small-to-large earthquakes (1012< M0 <1021 Nm) occurred in the Vrancea (Romania) seismogenic zone is considered in order to analyze the parameters which control the high-frequency decay of accelerations. To this aim, a large amount of new and high-quality earthquake data is considered. It includes multiple recordings recently obtained through the progress of seismic networks on the Romanian territory within the cooperation programme with the University of Karlsruhe (Germany): Collaborative Research Centre 461 programme (Bonjer et al., 2000) and temporary experiments, such as tomography experiment CALIXTO'99 (Wenzel et al., 1999) and urban seismology experiment URS (Ritter et al., 2005). The two relative methods are applied to pairs of collocated events and similar focal mechanism, in order to inspect the source and scaling properties over the seismic active depth domain generating Vrancea strong events (60-180 km). As our study shows, the high-frequency decay process is controlled and depends on distance, earthquake magnitude and site effects. Possible differences in the spectral characteristics in relation with Vrancea subducted lithosphere segments are also analyzed in correlation with the recent geodynamic modelling of the region.

## SITE CLASSIFICATION ASSESSMENT FOR ESTIMATING EMPIRICAL ATTENUATION RELATIONSHIPS: THE CASE OF NORTH-CENTRAL ITALY REGIONS. – ID 1719

*M. Massa, INGV, Italy*
*S. Marzorati, INGV, Italy*
*E. D'Alema, INGV, Italy*
*D. Di Giacomo, INGV, Italy*
*P. Augliera, INGV, Italy*

The aim of this work is to investigate the ground motion attenuation of the most industrial and populated regions of Italy evaluating in particular the capability of different approaches to estimate site dependent models. The data set includes 243 earthquakes (Ml 2.5-5.2) recorded from December 2002 to October 2005. Empirical attenuation relationships have been estimated for PGHV, PGHA, PGHD and SA for periods between 0.1 and 2.1 sec. To estimate suitable attenuation models, in particular for sites characterized by thick sedimentary covers, the discrimination of sites based on EU8 soil classes leads to wrong evaluations. On the contrary, site coefficients estimated through an ambient noise analysis (NHV) allow the models to fit better real and predicted data and to reduce the uncertainties of the process. For each receiver NHV have been strengthened by additional H/V spectral ratio of earthquake data (EHV), calculated considering different portions of the signals. A further test has been performed in order to compare the capability of classical methods used to estimate site dependent model to that of an alternative approach, tested for the area of interest, based on the introduction of the re-calculated station magnitudes (without considering station corrections) in the source term of the attenuation models. For magnitudes and distances of our data set, the trend in the variations of Wood-Anderson amplitudes can be related to different local site conditions. Such an approach, even if it provides models strictly predictive for sites where receivers are installed, allows both to fit better real and predicted data and to improve the standard deviations (up to 24%, 28% and 31% for PGHA, PGHV and PGHD). In particular for SA, this approach could represent a tool to forecast ground motions for sites where a large difference between observed and predicted peaks has been verified.

## DYNAMIC STRESS CHANGES DURING THE 2000 TOTTORI-KEN-SEIBU EARTHQUAKE INFERRED FROM STRONG MOTION DATA – ID 1747

*H. Taniyama, Saitama University, Japan*

Dynamic shear stress changes during the 2000 Tottori-ken-seibu earthquake are examined. We assume that the earthquake had a single vertical fault plane and the fault plane is divided into 60 subfaults (2.25km long and 2.25km wide). Stress on subfaults is assumed to change at certain time intervals. Ground motions due to a stress change on each of the subfaults are calculated by FDM and they are used to compute synthetic waveforms. Time histories of shear stress change on the subfaults are determined by waveform inversion using strong motion seismograms recorded at 8 stations near the hypocenter. The observed and synthetic waveforms are bandpass filtered between 0.1Hz and 1.0Hz. To stabilize the inversion, we add smoothing constraints on the spatio-temporal stress distribution and the positivity constraint on slip. The result shows that stress change in the strike direction is dominant. It is also observed that large stress drop occurs in the upper central part of the fault. Negative stress drop is observed at the NW and SE sides of the fault at depths between 5 and 10km. The stress drop and fault slip distributions obtained in this study generally agree with those obtained from kinematic models (Iwata and Sekiguchi, 2002; Dalguer et al., 2002). The stress change histories in the high stress drop zones show predominantly monotonic stress drop.

## GROUND MOTION SIMULATION IN THE GRENOBLE BASIN USING EMPIRICAL AND NUMERICAL GREEN'S FUNCTIONS – ID 1758

*M. Causse, LGIT, France*
*E. Chaljub, LGIT, France*
*F. Cotton, LGIT, France*

The ability of the empirical Green's functions (EGFs) method to simulate ground motion, including site effects, is now well established. Nevertheless it remains often difficult to assess the low-frequency part of the ground motion (<0.5-1 Hz), owing to the bad signal-to-noise ratio of the EGFs. Therefore we propose to combine the EGFs method with a 3D spectral elements method. First we create a synthetic Green's function by summing both empirical and numerical Green's functions in the temporal domain. Second we simulate ground motion with a kinematic EGFs

approach. The kinematic model is defined with (1) a modified k2 slip model , taking into account the recent knowledge obtained through kinematic inversion models (Mai et al., 2004; Manighetti et al., 2005), (2) a circular rupture front propagating at constant velocity, (3) a source-time function compatible with earthquake dynamics (Tinti et al., 2005) on each subfault. We use this method to simulate broadband (0-40 Hz) ground-motion time histories in the Grenoble basin for a potential MW 5.5 earthquake on the Belledonne fault.

### SYNTHESIS STRONG GROUND MOTION ESTIMATED BY USING EMPIRICAL GREEN FUNCTION FOR TEHRAN REGION – ID 1792

*M. Famili, Azad University(Noshahr-Chalus Branch), Iran (Islamic Republic Of)*
*A. Mahdavian, Shahid Abbas-Pour University, Iran (Islamic Republic Of)*

Tehran Area is located at the foot slope area of the Alborz Mountains. This zone is one of high seismic potential with many peculiar active faults. The urban area of Tehran has been developed on alluvial layers. According to historical seismic data, this city has suffered several strong earthquakes. Seismologists predicted a strong earthquake will be happen in Tehran in the near future. The city has not experienced a catastrophic earthquake since 1830. The Peak Ground Acceleration was calculated more than 0.4g for Tehran, due to the happened earthquake in 855 Ray. It has also been suggested that this may have occurred at the South/North Ray fault located in the sought of Tehran. Acceleration time history of future earthquake can simulate by several methods. In this study observed earthquake motion modeled by the convolution of slip distribution in time and space domain as the fault surface and the response of materials in propagation pass for unit slip (Green's FUNCTION). It is based on using small event instead of theoretical one to calculate large event along the faults around Tehran. Finally the waveform of the scenario earthquake was synthesized by using Empirical Green's Function.

### ATTENUATION MODELS FOR HAZARD STUDIES IN WESTERN IBERIA – ID 1801

*S. Vilanova, Instituto Superior Tecnico, Portugal*
*J. Fonseca, Instituto Superior Tecnico, Portugal*
*C. Oliveira, Instituto Superior Tecnico, Portugal*

As in most moderate seismicity regions, the ground motion database for Portugal is composed of low magnitude events at short to medium distances and moderate magnitude events at medium to large distances. However, either from historical accounts (e.g. the Lisbon 1755 earthquake) or from paleoseismological studies (Vilariça and Lower Tagus Valley faults)a regional potential to generate large to very large magnitude earthquakes is in general recognized. Western Iberia is a region of confluence of distinct crust types - oceanic, stable continental and active continental - and it is not clear which ground motion models are most suitable for hazard studies. The Ambraseys et al. (1996) model, widely used in European seismic hazard studies, was empirically derived using data from active Europe and Middle East. Attenuation relations for stable continental regions, like the models of Atkinson and Boore (1997) and Toro et al. (1997) for Central and Eastern North America, are usually based on stochastic simulated data. Ground motion models have a critical influence on seismic hazard: for Portugal, the maximum PGA values for 475 years of return period are 0.08g, 0.15g and 0.24g using the three attenuation models cited above (Vilanova, 2004). In this work an effort is made towards the characterization of ground motion attenuation in Western Iberia by using both the available ground motion data and macrosseismic data converted to ground motion parameters through empiric models. Contrary to what would be inferred from the criteria of Johnston (1989), our results do not suggest that the attenuation in the active region (the Azores-Gibraltar plate boundary SW of Iberia) is higher than in the stable crust. The Ambraseys et al. (1996) attenuation model used in the hazard studies of Jimenez et al. (2001) seems to underestimate the ground motion for this region.

### EVALUATION OF 3D VELOCITY STRUCTURE MODELS OF MARMARA BASED ON FDM SIMULATION OF GROUND MOTION FROM MW 4.1 EVENT – ID 1872

*G. Birgoren, Bogazici University, KOERI, Turkey*

Significant damage to structures and loss of life in Istanbul metropolitan area during the 1999 Kocaeli Earthquake revealed the necessity of much detailed analyses of seismic hazard for a future large earthquake. Development of the three dimentional velocity model that is capable of accurately simulating the effect of deep and shallow sediments on ground motion from a fault system nearby the city is a key issue to assess the ground motion expected in the city of Istanbul. In this study, recent investigations of the subsurface geological structure in Eastern Marmara, including, tomographic inversion results, borehole information and microtremor results were compiled and a rough 3D velocity model was constructed by a linear interpolation. The model occupies a volume of 120x6030km with a grid spacing of 0.5km in horizontal and vertical directions, except the areas underlain by thick Quaternary sediments where the shallow shear wave velocities are as low as 400m/s. In those regions vertical grid spacing was chosen as 0.15km down to a depth of 0.60km. The simulation was accomplished by a finite difference method using staggered grids with variable spacing in the vertical direction. Capacity of the model was judged by comparing recorded/simulated ground motion velocities from Mw:4.1 event recorded at 86 stations in Istanbul. Preliminary results indicate that the both amplitude and phase of the observed waveforms can be successfully simulated up to 0.5Hz particularly at the central and northeastern part of the city. Overall features of the waveforms recorded at stations overlain by deep sediments, where the shallow shear wave velocities are well designated at northwestern part of the city, were caught by the model. Difficulties to match the simulated/observed ground motion at particular sites might arise from the uncertainty in the velocity model and uncertainty in focal mechanism solution of the event.

### DOMINANT PERIODS OF LONG-PERIOD STRONG GROUND MOTION IN KANTO BASIN OBTAINED BY H/V SPECTRAL RATIOS OF SEISMIC RECORDS – ID 1950

*H. Cruz, Institute of Engineering, UNAM, Mexico*
*T. Furumura, ERI, University of Tokyo, Japan*
*F. J. Chavez-Garcia, Institute of Engineering, UNAM, Mexico*

Recently several big earthquakes characterized by long-period strong ground motion have occurred in Japan and have shaken Kanto basin considerably. This make possible the excitation of its deep structure, and dominant periods can be determined by analyzing ground motion records of stations (K-net, KIK-net and SK-net) installed widely on its surface.

Two earthquakes were analyzed: Niigata-ken Chuetsu earthquake (Mj 6.8, Oct. 23, 2004; predominant period 8 s) and Kiihanto Nanto Oki earthquake (Mj 7.4, Sep. 5, 2004; 12 s); a total of 524 seismic stations for Chuetsu earthquake, and 330 for Kiihanto earthquake were used. Dominant periods were obtained at each station by using 1) velocity response spectra for 5 % damping (VRS) in a period band between 0.2 to 40 s, and 2) H/V spectral ratios (SR).

VRS do not show any peak at periods longer than 8 s during the Chuetsu earthquake, while SR do. For Kiihanto earthquake, peaks agree well for spectra determined by both techniques, even for periods longer than 8 s. It was also observed that in spite of differences in Fourier spectra due to both earthquakes, SR give the same dominant period (within 20%) at the same station regardless of the predominant period of the input motion. The reason is that VRS depend mainly on the predominant period of input motion, while SR depend on the response of the basin itself. Therefore, dominant periods at each station were taken from SR due to its stability. Dominant periods in Kanto basin range from 3 to around 13 s, and they show a linear relation with the thickness of sediments

obtained by previous reflection/refraction surveys. Dominant periods are important for design structure purposes and site effect evaluation.

### ATTENUATION RELATIONSHIPS IN NORTH WESTERN ITALY CALIBRATED USING WEAK MOTION DATA – ID 1989

*S. Barani, Dip.Te.Ris.-University of Genoa, Italy*
*D. Bindi, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*G. Ferretti, Dip.Te.Ris.-University of Genoa, Italy*
*D. Spallarossa, Dip.Te.Ris.-University of Genoa, Italy*

We present ground motion models calibrated for North Western Italy using weak motion data recorded by the RSNI seismic network managed by the University of Genoa (http://www.dipteris.unige.it/geofisica). We consider more than 18000 waveforms relevant to 343 earthquakes recorded by 19 stations. The present study consider the earthquakes that occurred between January 1998 and April 2006 in the North Western Alps and in the Northern Apennines between 43.6° N-45.8° N, and 7.0° E-10.5° E. The ground motion models are derived for peak ground velocity (PGV), peak ground acceleration (PGA), and spectral acceleration (SA), using a standard damping of 5% at 14 frequencies between 0.5 and 25 Hz. The attenuation relationships are derived for both the larger horizontal component and the vertical one, in the local magnitude range 2.1-5.1 and for hypocentral distance up to 290 km. We used the random effect model (e.g., Abrahamson and Youngs, 1992; Joyner and Boore, 1993) to estimate the component of variance related to the earthquake-to-earthquake, station-to-station and record-to-record variability. The inter-station distribution of error is used to investigate the presence of significant site effects, that have been checked independently using the site transfer functions obtained by applying the generalized inversion technique (Castro et al., 1990). Finally, the considered data set is used to evaluate the goodness-of-fit of regional attenuation relationships previously derived for different areas in Italy (e.g., Umbria-Marche and Molise), by applying the maximum likelihood approach proposed by Scherbaum et al. (2004).

### CHARACTERISATION OF SEISMIC RESPONSE USING MULTI-DEGREE OF FREEDOM INELASTIC RESPONSE SPECTRA – ID 2073

*S. Wilkinson, University of Newcastle, UK*
*R. Hiley, University of Newcastle, UK*

This paper presents the results of response history analyses of multi-storey framed buildings. Regular structures were analysed and the effects of number of stories, period; and ductility were investigated. The results are presented in the form of multi-degree of freedom inelastic response spectra (MIRS). These spectra give insight into both the behaviour of structures and the characteristics of earthquakes that significantly affect their destructive capacity.

The model used, considers both material and geometric non-linearities. Inelastic behaviour of the structure was incorporated by using an extended perfectly elastic, perfectly plastic moment rotation relationship in the beams, at the beam-to-column connections. The elasto-plastic model was extended by introducing an ultimate failure state. While the plastic deformation is less than a critical value, a connection behaves rigidly/plastically, as soon as the critical value is reached the connection fails, that is, it loses any capacity to transmit a moment; it becomes 'pinned'. Within the constraints of the modelling assumptions, MIRS are believed to be a useful way of determining behaviour factors for exploring the limitations of SDF spectral methods.

## ES 3b: Structural Engineering - Bridges
Level-1

### SOME PECULIARITIES OF BRIDGES PERFORMANCE BASED DESIGNING (PBD) – ID 33

*I. Kuznetsova, Petersburg Transport University, Russian Federation*

Now all over the world performance based designing (PBD) is becoming the main method in the bridge earthquake engineering. However, up to now many important questions of PBD are not quite clear. Some of them are considered in the paper. Estimating the level of design seismic input is determinant for structure designing. For PBD it is necessary to set a number of such levels, two at least, i.e. those of operating basis earthquake (OBE) and maximal design earthquakes (MDE). The levels of these loads depend on the structure responsibility, which is set without any quantitative estimation. We offer an objective criterion of bridges responsibility, determined by occurrence probability of the mobile load on the bridge. Estimating combinations factors for seismic and mobile loads for long bridges calculation is especially important. It is given in the paper. The bridge design diagram depends on, whether resistance forces in movable bearings and the roadway are overcome under seismic loadings. In roller and sector bearings friction forces are always overcome and in flat and tangential bearings are not overcome for OBE. In the letter case the bridge is the united frame system. In other cases the analysis of the bridge behavior is necessary. In bridges calculating it is important to take into account free-running piers excitation. This effect is considered in the paper. Besides calculating bridges stability and durability, PBD demands an additional analysis of two limiting conditions: spans downfall and a train crash. To analyze these limiting conditions, kynemaic bridge calculation for MDE and calculations of the bridge track and rolling-stock both for the OBE and MDE are necessary. They are analysed in the paper. The author thanks professor A.M.Uzdin for his help in the work.

### SEISMIC RESPONSE ANALYSIS FOR THE GIRDER BRIDGES WITH HIGH PIERS – ID 145

*K. Wang, Research Institute of Highway, China*
*Q. Li, Research Institute of Highway, China*

At present, researches about the design and construction of the bridges with high piers appear more and more in China. In this paper, seismic responses of two prestressed reinforced concrete bridges with high piers were analyzed. One is continuous-rigid girder bridge and is composed of four spans, which are (65+2×115+65) meters long, and the height of the three piers is 94m, 68m, 38m respectively. The other is rigid girder bridge and is composed of three spans, which are (94+170+94) meters long, and the height of the two piers is 95.5m, 53.5m respectively. Dynamic analysis for both of them used widely in bridges with high piers will direct the seismic design of such bridges. Dynamic characteristics of the structures which affect the dynamic response directly were analyzed and the characters of such bridges were concluded first; and then spectrum response method and time-history analysis were adopted to calculate the dynamic response, the results in the longitudinal and transverse direction were compared in detail, at the same time, the influence of the pile-soil action were discussed.

### TWO DIMENSIONAL NONLINEAR ANALYSIS OF SEMI-INTEGRAL ABUTMENT BRIDGE UNDER NEAR FAULT EARTHQUAKE LOAD – ID 148

*S. Nayeri, Tabriz university, Iran (Islamic Republic Of)*
*M. Barghian, Tabriz university, Iran (Islamic Republic Of)*
*M. Yousefzadeh, Tabriz university, Iran (Islamic Republic Of)*
*J. Safadoust, Tabriz university, Iran (Islamic Republic Of)*

Bridges form important link in the transportation system of a country .Bridges are also considered to be structures of post earthquake importance because of their need for emergency response, relief and rehabilitation measures. It is known from

experience that bridges are vulnerable to earthquake damage. Thus the safety and protection of bridges in earthquake is utmost important. There are number of bridges which are designed according to old codes whereas recent seismic provisions were not developed. Such bridges are mostly found deficient and may need seismic retrofitting. The occurrence of large earthquakes close to fault is inevitable and one kind of bridges that needs more investigation is semi-integral bridge.

This paper presents results of two-dimensional nonlinear analysis of semi-integral abutment bridges under near fault earthquake loading. The analyses were performed on a nonlinear dynamic finite element(FE) model using the computer program PLAXIS. Four earthquake acceleration records with various amplitudes of velocity pulses were used as input ground motions in the analyses. Results of the analyses indicate that the input motions with strong velocity pulses may cause excessive displacements of the bridge superstructure and abutments. The objective of this research is to investigate the response of the bridge to a near field earthquake loading taking into account the soil-structure interaction effects.The present research investigate the response of the bridge due to nearfield earthquake loading taking into account the soil structure interaction effects.

Keywords: Semi-Integral abutment bridge; Soil-structure interaction; Dynamic analysis; Near fault ground motion.

## EXPERIMENTAL ASSESSMENT OF DYNAMIC CHARACTERISTICS OF A NEW PRESTRESSED CONCRETE BRIDGE UNDER VARIOUS EXCITATION – ID 149

*Y. Zaslavsky, Geophysical Institute of Israel, Israel*
*I. Minkin, 2Yaron-Shimoni-Shacham consulting engineers LTD, Israel*
*M. Rabonovich, 2Yaron-Shimoni-Shacham consulting engineers LTD, Israel*
*N. Perelman, Geophysical Institute of Israel, Israel*

Kfar Daniel Interchange Bridge of the Cross-Israel Highway has the following features: overall bridge lengths about 180m; 18.25m uniform width; 6 spans with length in the range of 27.0-39.6 m; horizontal highway alignment - uniform radius curve, R 675 m; the bridge superstructure is a hollow concrete cast-in-situ slab, 1.5m thick, with longitudinal and transverse prestressing. The present work is focused primarily on determination of the bridge dynamic characteristics in the vertical direction. To determine vibration modal shapes, the vertical vibration of the deck was monitored at 12 locations along its length. Torsion tests were included by placing seismometers on opposite sides of the deck. We carried out dynamic response tests for various means of excitation: passage of a four axle, heavy truck traveling at a constant speed of 90 km/hr; impact of a heavy truck crossing a board and the effect of abrupt braking; impact by a dynamic source consisting of a truck-mounted, drop-weight striking vertically low amplitude vibrations produced by ambient excitations. Two torsional natural frequencies and the first five flexural natural frequencies of the bridge vibrations in the vertical direction were identified. To obtain theoretical natural frequencies, the entire structure was simulated in a finite elements model utilizing shell and beam elements. The comparison between numerical and experimental results showed very good agreement. Dynamic characteristics experimentally obtained by spectral analysis techniques are useful for comparison with results of future periodic tests. Repeated measurements may be used to detect changes in the dynamic properties of the structure which, in turn, indicate changes of the structural condition and potential defects. It should be noted that dynamic parameters obtained from vertical vibration of a bridge are not significantly influenced by various environmental effects such as changes in temperature or soil conditions including ground water level changes.

## THE PERFORMANCE OF INTEGRAL-ABUTMENT BRIDGES AND THE GEOSYNTHETIC TENSILE REINFORCEMENT BACK-FILL – ID 152

*S. Nayeri, Tabriz university, Iran (Islamic Republic Of)*
*M. Barghian, Tabriz university, Iran (Islamic Republic Of)*
*M. Yousefzadeh, Tabriz university, Iran (Islamic Republic Of)*
*J. Safadoust, Tabriz university, Iran (Islamic Republic Of)*

The integral-abutment bridge (IAB) concept was developed at least as far back as the 1930s to solve long-term structural problems such as bearings and expansion joints which are fragile elements and represent the weakest links in bridge structures. One of the main features of these bridges is the continuous and integral connection of the bridge deck with abutments, eliminating the need for expansion joints, thus improving aesthetics, increasing durability as well as reducing maintenance requirements. Integral bridges have been studied during last decades and in design codes, they have been paid less attention to the seismic treatment of these bridges. Therefore , in many ways integral bridges are a big challenge to the structural designer and at present must be considered as the final frontier for small and medium length bridges. It utilizes geosynthetic tensile reinforcement (likely geogrids or geotextiles ) to create a mechanically stabilized earth (MSE) mass within the retained soil adjacent to each abutment. The analyses were performed on a nonlinear dynamic finite element(FE) model using the computer program PLAXIS. Two earthquake acceleration records with various amplitudes of velocity pulses were used as input ground motions in the analyses. The objective of this research is to investigate the response of the bridge to a near field earthquake loading taking into account the soil-structure interaction effects between abutment and the geosynthetic tensile reinforcement back-fill systems.

The present study has been limited to symmetrical integral bridges with no skew and the abutments are supported by driven piles. A fixed connection is assumed between the piles.

Keywords: Integral abutment bridge; Soil-structure interaction; Dynamic analysis; Near fault ground motion; geosynthetic tensile reinforcement back-fill systems.

## SEISMIC BEHAVIOR OF JOINTLESS LINK SLAB BRIDGES – ID 262

*A. Vasseghi, IIEES, Iran (Islamic Republic Of)*
*F. Nateghi, IIEES, Iran (Islamic Republic Of)*
*M. Pournadaf Haghi, IIEES, Iran (Islamic Republic Of)*

Highway bridges are frequently constructed as simple span structures with prestressed concrete girders and a cast-in-place concrete deck spanning from one pier or bent to another. At each end of simple-span deck a joint is provided for deck movement due to temperature, shrinkage, and creep. Bridge deck joints are expensive and pose many problems with regard to bridge maintenance. Elimination of deck joints at support of multispan bridges has been the subject of recent studies. Research by Caner and Zia (1998) led to development of a design concept and design approach for jointless bridges where the locations for expansion joints are replaced with continuous link slabs. Further study of an instrumented link slab bridge indicated proper performance of such bridges under service loading conditions. This paper presents the results of an analytical study on seismic behavior and response of two span bridges connected by link slabs. Three dimensional finite element analyses of straight and skew bridges with skew angles varying from 0 to 60 degrees is used for this study. Both linear time history and response spectrum analyses method were carried out to investigate the response of bridges. The response of link slab bridges are compared with that of simply supported bridges with an expansion joint. The results of analyses are also compared with Eurocode's seismic design requirements.

## CONSTRUCTION OF CONTINUOUS GIRDER BRIDGES IN SEISMIC REGIONS OF RUSSIA – ID 267

*G. Shestoperov, Moscow State Railway University, Russian Federation*
*E. Balutchic, Scientific Research Institute of Transport Constru, Russian Federation*
*V. Seliverstov, Giprotransmost Joint Stock Co., Russian Federation*
*V. Stepanov, Giprotransmost Joint Stock Co., Russian Federation*

Normally the bridges of continuous system are adopted for construction of bridge crossings over the large rivers, viaducts and town overpasses with a typical span range from 80 to 150m. Superstructures are built of prestressed concrete, steel or composite (steel/concrete) having an overall length of continuous system within the limit of 1000m. The paper covers special structural solutions of piers with a height of up to 70m, seismic de-vices, including dampers and some other bridge elements in seismic regions of Russia. Meth-ods for analyzing bridge structures when subjected to earthquake loads, seismological works at bridge construction sites and methods of quality control of construction works are presented also. Examples of built structures in Northern Caucuses and Siberia are given.

### STOCHASTIC SEISMIC RESPONSE OF THE HUMBER SUSPENSION BRIDGE TO SPATIALLY VARYING GROUND MOTIONS – ID 300

*S. Adanur, Karadeniz Technical University, Turkey*
*K. Soyluk, Gazi University, Turkey*
*A. Bayraktar, Karadeniz Technical University, Turkey*
*A. A. Dumanoglu, Karadeniz Technical University, Turkey*

In this paper, a comprehensive investigation of the stochastic response of The Humber Suspension Bridge in Humberside in England subjected to spatially varying ground motions is performed. The spatially variability of ground motions is considered with incoherence, wave-passage and site-response effects. The importance of the site-response effect, which arises from the difference in the local soil conditions at different support points of the structure, is investigated particularly. Filtered white noise (FWN) ground motion model modified by Clough and Penzien is used as a ground motion. Firm, medium and soft soil types are used for an example bridge and the filter parameters for these soil types proposed by Der Kiureghian and Neuenhofer are utilized. The incoherence effect is examined by taking into account Harichandran and Vanmarcke model. The wave-passage effect is investigated by using 400m/s wave velocity for soft soil, 700m/s wave velocity for medium soil and 1000m/s wave velocity for firm soil. The Humber Suspension Bridge connects the towers of Hessle and Barton across the Humber Estuary upstream from Hull. It has inclined hangers and its main span of 1410m, with side spans of 280m and 530m on Hessle and Barton sides, respectively. Mean of maximum and variance response values obtained from the spatially varying ground motions are compared with those of the specialised cases of the ground motion model. It is pointed out that each component of the spatially varying ground motion model has important effects on the dynamic behaviour of the structure. Therefore, to be more realistic in calculating the bridge responses, the variability of the ground motions should be incorporated in the analysis of suspension bridges.

### SEISMIC PERFORMANCE OF CURVED VIADUCTS WITH UNSEATING PREVENTION CABLE RESTRAINERS – ID 353

*F. D. Ruiz Julian, Hokkaido University, Japan*
*T. Hayashikawa, Hokkaido University, Japan*

The widely recognized susceptibility to seismic damage of horizontally curved highway viaducts is substantially amplified with the rupture of continuity of the superstructure at expansion joints. The increasing need for safer bridges has stimulated the adoption of a common protection strategy consisting in the replacement of the vulnerable steel bearing supports with seismic isolation devices. Moreover, isolated viaducts can be seismically upgraded through the installation of cable restrainers that provide connection between adjacent spans. While the effects of cable restrainers are well understood for straight bridges, it is not clear how effective this unseating prevention measure is for isolated curved bridges. This is due to the considerable complexity associated with seismically induced joint movements, which may occur in both tangential and radial directions. In addition, the current design methodology, based on static analysis procedures, is not able to ensure the ability of restrainers to resist the high demands generated by near-fault earthquake motions. Therefore, the aim of this study is to investigate the advantages that cable restrainers provide to improve the performance of isolated curved viaducts subjected to strong earthquake excitations. For this purpose, seismic responses are calculated on a three-dimensional non-linear bridge model using an analytical method based on the elasto-plastic finite displacement dynamic response analysis, considering both geometric and material non-linearities. An innovative trilinear analytical model of the isolators has shown its ability to accurately represent the bearing behaviour at high strains. Furthermore, the unseating prevention restrainers are bi-directionally modeled to simulate yielding and failure of the cable. The calculated results have shown that adequate cable restrainers are able to minimize the possibility of deck unseating, eliminating pounding and residual joint separation damages. The investigation results provide sufficient evidence and excellent basement to ensure the appropriate selection of cable restrainers according to characteristics of the isolation system.

### ESTIMATION OF MAXIMUM IMPACT FORCE ON NATURAL RUBBER DURING COLLISION OF TWO STEEL BARS – ID 488

*Y. Kajita, Kyushu Univ., Japan*
*T. Kitahara, Kanto Gakuin Univ., Japan*
*Y. Nishimoto, Shibata Industrial Co. Ltd., Japan*
*H. Otsuka, Kyushu Univ., Japan*

In the Japanese Specifications for Highway Bridges, shock absorbing rubbers for bridge restrainer system are required. The design load of shock absorbing rubbers is set to be 1.5 times as the weight of a girder. However, it has been clarified that the maximum impact load depends strongly on the collision velocity of two bodies. Therefore, we were carried out collision tests between two steel solid bars using a new experimental apparatus in order to investigate the relationship between the maximum impact force and the collision velocity. This new apparatus can levitate a steel bar by using compressed air so that there is little friction between a steel bar and a guide rail against the horizontal movement. We name this apparatus as "frictionless impact testing apparatus". The steel bar has 1000mm long, 200mm wide, 200mm high and about 3.0kN weight and the thickness of shock absorbing rubbers ranges from 10mm to 40mm and the collision velocity ranges from 0.2m/sec to 1.3m/sec on 5 stages. We make an estimated formula of the maximum impact force on natural rubber during the collision on the basis of the test results and we also carry out some simulation analyses in order to confirm the validity of the proposal formula. From the test results, it is found that the maximum impact force is proportionate to the square of the collision velocity and the reduced mass of two steel bars. Moreover, from the simulation analyses, it is confirmed that the maximum impact force is proportionate to the square of the collision velocity; however it is difficult to estimate the maximum impact force because it is hard to express the strain rate effect of the natural rubber appropriately.

### SEISMIC RELIABILITY ANALYSIS OF CABLE-STAYED BRIDGE CONSIDERING ENTIRE-BRIDGE SYSTEM – ID 491

*A. Furukawa, Kyushu University, Japan*
*H. Otsuka, Kyushu University, Japan*
*Y. Suzuki, CTI Engineering, Japan*
*T. Betsumiya, Kyushu University, Japan*

Structures contain a lot of uncertain factors, such as variations in material and geometrical characteristics. Reliability analysis evaluating variations in structural performance caused by these various variation factors is therefore very important. It is also meaningful to analyze seismic reliability of the entire system if the structures are large-scaled showing complex behavior during earthquakes. This study conducted the reliability analysis of a cable-stayed bridge and evaluated its seismic performance using damage indices which account for (a) maximun deformation; (b) cumulative damage; (c) both maximum deformation and cumulative damage. First, the structural reliability considering uncertain

material characteristics was analyzed using the entire bridge system and its single pier model, and the results were compared. Next, the sensitivities between structural properties and damage indices were examined. Finally, reliability analysis considering uncertain input ground motions was examined. The Japanese design specification for highway bridges defines the design earthquake motion as acceleration response spectra, and there are infinite numbers of waveforms which meet the same designed spectra with different phase characteristics. Therefore, Monte Carlo simulations using simulated earthquake motions, which has the same acceleration response spectra and different phase characteristics, were conducted. The difference in structural damage indices was found to be due to the difference in non-stationarity of input ground motions through time-frequency-analysis.

### SEISMIC RETROFITTING OF CONCRETE BRIDGES – ID 580

*M. Causevic, University of Rijeka, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*
*M. Bulic, University of Rijeka, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*

Bridges which were built before 1970s, either in U. S. or Japan or Europe, had been designed with little or no consideration for seismic demand. Majority of these bridges are supported on reinforced concrete bents and pier walls that lack the ductility and strength to resist earthquakes. Meanwhile strong motion earthquakes revealed all vulnerable places on each of those bridges if built in seismically active region. After the 1971 San Fernando earthquake U. S. started several seismic retrofit programs. Retrofit programs in the 1980s included the first use of isolators on bridges and a program to retrofit single-column bents. These programs were greatly accelerated after the 1989 Santa Cruz (Loma Prieta) and 1994 Northridge earthquakes. After the 1994 Northridge earthquake, it was observed that no serious damage would have occurred if the previous retrofit program had already been implemented. Japan also started similar programs, especially after the 1995 Kobe earthquake. Some solutions for retrofitting the abutment, bent and column of concrete bridges recommended in these programs as well as some recommendations and comments made by authors will be presented in this paper.Structural retrofitting is becoming more and more important and received today considerable emphasis throughout the world.Europe may not be out of this global problem and must have own retrofit program not only for buildings (Eurocode 8, Part 3: Strengthening and Repair of Buildings, 2003) but for bridges as well.

### SEISMIC FRAGILITY ANALYSIS OF HARP TYPE CABLE STAYED BRIDGES WITH SUPPORT FLEXIBILITY – ID 601

*R. A. Khan, Jamia Millia Islamia, India*
*T. K. Datta, Indian Institute of Technology, India*
*S. Ahmad, Indian Institute of Technology, India*

A seismic fragility analysis of harp type cable stayed bridges with support flexibility is presented which can be used for preliminary estimate of its probability of failure. The risk analysis procedure uses the format of Probabilistic Risk Analysis (PRA) and considers the band limited white noise at the bedrock as the seismic input. The bridge deck is modeled as a beam supported on springs at different points. The coupled stiffness matrix of the springs is determined by a separate 2D static analysis of cable-tower-deck system in which flexibility of the tower base due to soil-structure interaction is included. Damping due to soil is incorporated by the equivalent modal energy method. The response of the bridge deck is obtained by the response spectrum method of analysis for multi-degree of freedom system. The PRA includes uncertainties of responses due to the variation in ground motion, material property, modeling and method of analysis, and uncertainties of the capacity due to the variation of ductility factor and damage concentration effect. Failure mode of the bridge is assumed to be bending failure of the bridge deck at the point of maximum bending moment. Probability of failure of the bridge deck is determined by First Order Second Moment (FOSM) reliability analysis. A three span double plane cable stayed bridge is used as an illustrative example. The fragility curves for the bridge deck failure are obtained under a number of parametric variations. The parameters include, base flexibility, degree of correlation of ground motion, angle of incidence of earthquake, ratio of the components of ground motion. Study shows that flexible base condition provides significantly less value of probability of failure as compared to the fixed base. Further, angles of incidence, degree of correlation and ratio of components of ground motion have considerable effects on the probability of failure.

### DISPLACEMENT-BASED DESIGN OF CONTINUOUS CONCRETE BRIDGES UNDER TRANSVERSE SEISMIC EXCITATION – ID 720

*J. C. Alvarez Botero, Luis Gonzalo Mejia y Cia, Colombia*
*N. Priestley, ROSE School, Italy*

A displacement-based design procedure for multi-span reinforced concrete bridge structures when subjected to seismic action in the transverse direction is presented. The procedure, initially proposed by Priestley [Priestley, 1993], is reviewed and some improvements are implemented. The design methodology is applied to different possible bridge configurations. The accuracy of the method in terms of reaching the target displacements under the design earthquake level is then assessed using inelastic time-history analysis.

Dynamic amplification of the deck transverse moments is investigated and compared with analytical results using different variations of the modal superposition approach. What has been called the "Modified Modal Superposition", first introduced for cantilever walls, [Priestley, 2003], is then proposed as an effective method to account for higher mode effects on the deck transverse moment distributions.

### SEISMIC PERFORMANCE EVALUATION OF A STEEL ARCH BRIDGE – ID 727

*J. D. J. Alvarez, UMSNH, Mexico*
*S. Zavala, UMSNH, Mexico*
*J. Mejia, BICA, Mexico*
*M. Jara, UMSNH, Mexico*

This paper deals with the expected seismic response of Coronilla Viaduct, which promises to be, at the end of 2007, the longest arch span in Mexico. The bridge is an upper-deck arch bridge mainly composed of RC deck slabs, steel girders and columns, and single span steel arch ribs. The total length of the bridge is 273 m, and the two end-fixed steel arch has a span of 200 m with a rise at the crown of 34 m, giving a rise-span ratio of 1:5.9. The arch consists of three box-section ribs with both transverse bracings and diagonals connecting the three arch ribs at the spandrel column locations. The longitudinal girders and arch ribs are connected by vertical columns stiffened with transverse bracings and diagonals.

The bridge will be constructed in Morelia, Mexico, over a deep ravine, in a moderate seismic risk area. A commercial finite-element computer code was used for the 3D analysis of the bridge. The structure was analyzed and designed in compliance with Mexican practice; specifically, seismic assessment of forces and deformation demands was performed by means of an elastic dynamic analysis, that is, a modal spectral analysis, using the response spectrum proposed by the Mexican code and taking into account a number of modes sufficient to capture at least 90% of mass participation in the longitudinal, transverse and vertical directions.

In this study the inelastic behavior of Coronilla Viaduct subjected to ground motions is investigated by dynamic analyses. The input ground motions are accelerograms which are modified ground motions based on records from the Mexican Strong-Motion Database. Both the in-plane and out-of-plane dynamic characteristics of the bridge are studied by investigation of time-history responses of the main parameters.

### EMPIRICAL TORSIONAL HYSTERESIS MODEL FOR RC COLUMNS UNDER COMBINED CYCLIC BENDING AND TORSION – ID 791

*P. Tirasit, Tokyo Institute of Technology, Japan*
*K. Kawashima, Tokyo Institute of Technology, Japan*

During an earthquake, RC columns of some bridges with irregular configurations, for example bridges supported by C-bent columns and skewed bridges, are possibly subjected to the reversible bending moment, shear and axial load combined with torsion. However, the reliable torsional hysteresis model of RC columns which is necessary for the nonlinear seismic analyses of such special bridges has not been available yet. An experimental study on the effect of combined cyclic uniaxial bending and torsion on RC columns was conducted at Tokyo Institute of Technology. An empirical model for the torsional hysteresis of RC columns under combined cyclic bending and torsion with an axial load is proposed based on the regression analysis of the experimental results. The model is governed by a tri-linear hysteretic backbone which is composed of the linear elastic range, the constant restoring torsion range, and the deterioration range, cooperating with the proposed unloading and reloading rules. The main controlling parameter is the rotation-drift ratio r representing the level of combined action in term of the ratio between the lateral drift and rotation of column at the effective height. The effect of number of loading cycles is also taken into account in the model.

### ANALYTICAL STUDY ON POUNDING OF GIRDER END TO A BRIDGE THAT SUFFERED DISASTER WITH THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE – ID 846

*H. Tomohisa, Pacific Consultants Co.,Ltd., Japan*

In this paper, authors summarized the damage analysis result the highway bridge where the disaster occurred with the 2004 Niigata-ken Chuetsu earthquake. Among those structures, it was checked that a bridge showed characteristic disaster by damage on bridge pier with termination of main reinforcement or pounding of girder end. However, it was not clear that the present condition is the damage form or the evaluation of resistance characteristic to abutment by pounding of girder end. On the other hand, many researches on pounding of bridge girders were done. Next, damage analysis of each section was performed in detail for the bridge which actually suffered disaster. Based on the result of damage analysis, there is very little research aiming at evaluation of the damage mechanism in collision analysis. In this study, detailed analysis was performed about the damage situation of those structures. Subsequently, it verified about the damage mechanism in nonlinear dynamic analysis considering pounding of bridge girder. Then, this analysis case set up two cases of the case-1 in consideration of girder collision, and the case-2 where girder collision is not taken into consideration. Furthermore, horizontal resistance characteristic of abutment proposed the analysis model from the past experiment result. As the result of analytical examination, if horizontal resistance characteristic of abutment was taken into consideration, the horizontal displacement was controlled and the maximum response of bridge pier was also reduced. Therefore, it was found that it was not the damage in which a bridge pier collapsed.

### RESPONSE ANALYSIS ON BRIDGES SUPPORTED BY RC C-BENT COLUMNS – ID 855

*S. Nagata, Tokyo Institute of Technology, Japan*
*K. Kawashima, Tokyo Institute of Technology, Japan*

In urban areas, there exist various unique structures which require special consideration in seismic design due to their irregular structural placement. One such structure is a single column with the lateral beams being longer in one side than the other. They are called C-bent columns or inversed L-shaped columns. In C-bent columns, an eccentricity between the column center and the point where the deck weight applies results in a static eccentric moment. C-bent columns exhibits complicated seismic behavior due to the eccentricity. The eccentric moment results in more extensive failure in the eccentric compression side than the tension side of the columns under a strong excitation, and this failure mode results in a large residual displacement. Moreover, the eccentric inertia force in the longitudinal direction causes a combined bending and torsional loading. To evaluate such complicated seismic behavior of C-bent columns, 3-D idealization is required. Furthermore, effect of supporting conditions of a deck by bearings on the seismic torsion of the columns is important. In this study, to clarify the seismic performance of C-bent columns, 3-D dynamic response analysis under multi-directional excitation is conducted on a bridge system including a superstructure, bearings, columns, and foundations. An analysis on five-span continuous bridge consisting of fixed steel bearings, C-bent columns and pile foundations is first conducted, which shows the importance on the effect of the column eccentricity in the estimation of residual displacement of columns as well as the design of bearings. Effect of failure of the fixed bearings on seismic torsion of C-bent columns is also analytically investigated. In addition, effectiveness of elastomeric bearings such as rubber bearings in mitigation of the residual displacement of C-bent columns is clarified.

### SEISMIC BRIDGE DESIGN AND DETAILING IN QUEBEC, CANADA – ID 926

*V. Latendresse, Teknika-HBA, Canada*

The adoption of a new bridge design code in Canada in 2000 brought a large change in seismic design philosophy. It took a number of years to bring the modifications to there full application in the province of Québec. The Ministry of Transportation of the province acting on the demands of the provincial government determined strategic economic transportation links that should remain open after large seismic events. This deeply changed the lateral force design of bridges on and above these roads. This paper describes with the use of several example projects the application of this design philosophy and state of practice implementation of code rules. Specifically, the confinement requirements at the base of concrete piers, reinforcement of footings, foundation design are reviewed and compared to other accepted codes. Several detailing practices are described which have proved both economical and adaptable to existing construction practices in the province.

### ANTISEISMICS DEVICES IN BRIDGES – ID 990

*D. Cizmar, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*
*A. Nizic, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*

The bridge of Zeceva Draga is built in Croatia. Its total lenght is 940.8 m. It is in the horizontal curve. Its spans are 2x40+16x50+1x40. The columns are very tall, the tallest of them is 53 m high. Because the columns are extremely high, and the structure itself has a longer period, the application of elastomeric bearings on the bridge is not significant. Therefore, the bridge was calculated with the action of hydraulic dampers at the ends of the span structure towards the abutments. Time history analysis was calculated for accelerograms of magnitudes 5.5, 6, 6.5 and 7 with distances of 0 and 15 km from epicentre, based on earthquakes occurring in Petrovac, in April 1979, with magnitude of 6.8 and Ulcinj, in April 1979, with magnitude of 5.3, in the region of Adriatic coast. The damper was modelled using the Calvin's model. Since it is not a classical damping, the damping of the structure was calculated separately, and then the influence of the damper was added. Damping of devices is modelled depending on velocity. The daming of devices itself significantly reduces the force. The rigidity of the damper is apparent and it was used to simulate the elastic behaviour of the device because of the hydraulic compressibility.

In the laboratory of the Civil Engineering Faculty in Zagreb, the model with two spans was tested with and without dampers, in longitudinal and transversal direction, and it was proved that dampers increase the damping of the system.

The application of dampers is diverse, from silos, masts, towers, stands to bridges and factory chimneys.

### OHBA-OHASHI PILE-SUPPORTED BRIDGE EXPERIMENT REVISITED: PARADOXES AND NEW INTERPRETATIONS – ID 1131

*G. Mylonakis, University of Patras, Greece*
*C. Syngros, Langan Engineering, United States*

The seismic response of an actual bridge pier founded on a group of 64 steel piles in extremely soft clay is investigated. The pier and its foundation were thoroughly instrumented in the early 1980's by the Institute of Technology of Shimizu Corporation, which conducted seismic observations over a period of four years. The project provided several earthquake recordings, with peak accelerations in the free field as high as 0.11g. Two important observations were made: First, rock-to-surface amplification of peak horizontal acceleration exceeded 3 and varied significantly in the two horizontal directions, which is not compatible with the assumption of vertically-propagating S waves. The existence of a multi-dimensional wave field in Ohba Ohashi valley has been successfully demonstrated by several investigators. Second, the pile cap and bridge deck responded with a maximum acceleration of only 0.05g – as compared to an expected 0.15g or higher – a paradoxical behavior that has not been explained in a satisfactory manner to this day. An attempt is presented in this paper to reproduce structural response using analytical tools. The relatively low levels of peak shear strain in the soil (Epsilon $<$ 10-4) in conjunction with the high plasticity index of the clay and the lack of damage in the structure justify the use of elastodynamic models. The effects of soil amplification, kinematic interaction, foundation compliance and structural dynamics are considered. Pile group effects are treated with dynamic interaction factors accounting for wave interference phenomena among the piles. It is shown that records and predictions compare reasonably well when pertinent assumptions are introduced. Implications of valley effects, soil-structure-interaction, multiple-support excitation and structural connections on seismic response are discussed. The influence of kinematics of the movable bearings connecting the deck and the piers is investigated. A possible scenario for the surprising deamplification of earthquake motion at the structure is proposed.

### A PROCEDURE FOR SEISMIC HEALTH MONITORING OF BRIDGES – ID 1134

*K. Mirza, University of British Columbia, Canada*
*C. Ventura, University of British Columbia, Canada*

Seismic Health Monitoring (SHM) is defined here as the process of determining the adequacy of a structure to perform its function after being shaken by a severe earthquake. Modern communication technologies pertmit today monitor structures remotely, and it is of interest to make use of the collected information to implement a reliable SHM of a structure of particular interest. A primary topic of interest to structural engineers is the possibility of determining and assessing the extent of damage to an instrumented structure using data from a SHM program. In this paper, a procedure for damage detection is presented and evaluated. The procedure is based on a comparison between the structure's modal dynamic characteristics before and after the earthquake. The Damage Index Method (DIM) is presented and used to determine the location and the severity of damage to an existing well instrumented bridge, the Painter Street Overpass (PSO), which is located in California. This bridge has experienced more than ten earthquakes of different intensities and valuable strong motion data has been collected. In addition to the strong motion data, ambient vibration data is also available. A calibrated FE model of the bridge was developed using the ambient vibration results. This model was then used to perform pushover and nonlinear time history analyses. The results of nonlinear analyses were then used as feed data to the DIM to test its capability to detect different levels of damage. The paper shows that the SHM procedure is able to analyze the time histories recorded by the sensors mounted on a bridge after an earthquake and help determine the status of the structure.

### CYCLIC TESTS OF BRIDGE HOLLOW PIERS: NUMERICAL SIMULATION AND EXPERIMENTAL VALIDATION – ID 1206

*P. Delgado, Instituto Politecnico de Viana do Castelo, Portugal*
*N. Vila Pouca, Faculdade de Engenharia da Universidade do Porto, Portugal*
*P. Rocha, Instituto Politecnico de Viana do Castelo, Portugal*
*V. Rodrigues, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Arêde, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*
*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*

The objective of this paper is to compare the results obtained from an experimental campaign of reinforced concrete hollow piers, with different cross section under cyclic loading, with the analytical prediction. The fact that rectangular RC hollow piers have an particular structural behavior, close to structural wall, and therefore more difficult to predict with simple numerical tools, is the strong motivation of this work. In addiction, for different rectangular cross section dimensions, the interaction between the pier walls could affect their global behavior and damage. The numerical simulations of RC piers, representative of the typical bridge construction, as well as the application of non-linear cyclic analysis methodologies to evaluate the structural cyclic behavior are presented. These methodologies used within the scope of this work have several levels of complexity, from the more simple, based on a section fiber model, to the more refined, where sophisticated constitutive models are used, simulating the non-linear cyclic behavior of the concrete by a constitutive model based on the Continuum Damage Mechanics and using finite element discretization for the concrete and truss elements for the steel with a cyclic model. The aim is, therefore, to contribute for developing and calibrating of analytical tools that enables the evaluation of cyclic behavior of rectangular hollow piers, their advantages and limitations.

### THE EFFECT OF VERTICAL COMPONENT OF EARTHQUAKE ON CONTINUES AND MONOLITHIC FRAME BRIDGES – ID 1250

*A. Delnavaz, Amirkabir university of technology, Iran (Islamic Republic Of)*
*A. R. Rahaie, Amirkabir university of technology, Iran (Islamic Republic Of)*

Structural performance evaluation in recent decades' earthquakes shows that the effect of vertical component of earthquake (VCE) could be considered as one of the main causes of bridges fault. In most of bridge design codes, for seismic analysis of bridges, VCE is not taken into account or a distinguished method isn't presented for assessment of VCE. In the present work, the effect of VCE on two existing bridges, one with continues superstructure and the other with monolithic frame system, was studied. The first model consisted of a pre-stress bridge in witch the bridge superstructure was connected rigidly to piers. The superstructure had 3 spans with length of 16, 48 and 16 m. The end of side slabs was put on abutments. The second model was a bridge with steel deck and concrete piers. The bridge deck composed of I girder beams and in-place concrete slab. The beams were placed on 3 piers located 24 m far from each other, continually. In both models, the effect of VCE was studied considering the 3 acceleration of Tabas, Northridge and Kobe earthquakes and using linear and nonlinear time history and spectrum analysis on 3D models. In each analysis, the model was analyzed considering the 3 component and 2 horizontal components of earthquakes separately. The ratio of the difference of result in two analyses to the result of bridge response under its weight (DL) was compared. Finally, as analysis method mentioned above were compared, the amount of VCE effect on affected elements (according to statistical system of bridge) and the method of entering the VCE on bridge design has been discussed.

## SEISMIC RISK ASSESSMENT IN EGNATIA MOTORWAY LONG BRIDGES – ID 1268

*N. Theodulidis, Institute Engin. Seismology & Earthquake Engin, Greece*
*Z. Roumelioti, Geophysical Lab., Aristotle Univ., Greece*
*P. Panetsos, Egnatia Odos SA, Greece*

Egnatia Motorway as a lifeline has to be an efficient transportation system to play a vital role in the development of a modern society. Bridges are important lifelines sensitive to damage from earthquake ground-motion. Examples of societal consequences of bridge closure may be found in recent strong earthquakes worldwide (Loma Prieta 1989, Hyogo-ken Nambu 1995, Duzce-Kobe 1999).

More than six hundred and fifty (650) bridges represent the link between areas separated by rivers or other obstacles along the Egnatia Motorway and among them more than fifty have a length of more than 150m. The majority of these bridges are built in areas of moderate to high seismicity. In this study, seismic hazard in terms of PGA, related through the use of vulnerability functions to damage ratios for two typical long bridges, namely, Kavala-G2 (length 170m, height 50m) and Polimilos-G9 (length 170m, height 33m), is reassessed by determining new earthquake scenarios through the interpretation of ground acceleration and spectral values.

Based on certain bridge vulnerability functions and a regional seismicity model, probabilistic seismic risk assessment is firstly attempted for both sites, for mean return periods of expected damage ratio of 475years and 1100years. In a second step, synthetic acceleration waveforms are determined for selected earthquake scenarios due to well established near by seismic faults. Traffic and ambient noise data are used to assess and incorporate the variability of the site effect along the two bridges. Finally, synthetic PGA values are combined with the same bridge vulnerability functions used in the first step and seismic risk is reassessed.

Comparison between expected seismic risk results stemming from the aforementioned methods showed in some cases quite good agreement, while in other cases significant divergence was estimated. Reliability of the results of both approaches is discussed and combined risk scenarios for both bridges are proposed.

## ISSUES ON THE CAPACITY DESIGN OF TALL BRIDGE PIERS – ID 1322

*R. Ceravolo, Politecnico di Torino, Italy*
*G. V. Demarie, Politecnico di Torino, Italy*
*L. Giordano, Politecnico di Torino, Italy*
*D. Sabia, Politecnico di Torino, Italy*

Seismic behaviour of bridge structures often relies on the ductility and dissipation properties ascribed to vertical elements. In particular, when bridge piers are slightly affected by the deck's deformation, dissipation tends to concentrate in specific areas where the forma-tion of plastic hinges is expected. This phenomenon has been experimentally observed in slender reinforced concrete piers with compact section, even though in actual practice large box sections are of more interest in tall bridge pier design. Nevertheless technical reports on the effects of violent earthquakes on bridges hardly focused their attention on plastic mecha-nisms. In this paper, the tendency and modality of hinge formation and its influence on safety evaluation of bridge piers is investigated on a numerical basis. This objective entails an eva-luation of dissipation and ductility properties of pier sections, which will be performed through non-linear dynamic analysis. The model has taken into account the interaction be-tween axial and bending actions, as well as their dissipation properties under cyclic loadings. As a part of the examination, multimodal spectral analysis was used to design the sei-smic capacity of the bridge according to different capacity criteria . Linear analysis was com-pared with nonlinear dynamic analysis results to evaluate the capability of linear models to predict maximum earthquake ductility demands. The last part of the paper consists of the validation of current capacity design strategies and safety formats as applied to a typical tall bridge structure.

## AN ALTERNATIVE PROPOSAL FOR A "MOVABLE" ABUTMENT FOR INTEGRAL BRIDGES – ID 1377

*S. Mitoulis, Aristotle University of Thessaloniki, Greece*

The present investigation proposes a type of an integral abutment which can be implemented in short as also in long integral bridges. As alternative solution of the internationally implemented solution, of stub type abutments with flexible piles, the present paper proposes an abutment founded on micropiles which serve the needs of the in service movement of abutment's head, which movements result from the thermal expansion, contraction, creep and shrinkage of the deck. This abutment avoids the implementation of H-steel piles, which are internationally experimentally tested and promoted as they combine the advantage of flexibility and strength, as it is founded on flexible micropiles. The alternative proposal combines on the one hand a full height web, whose thickness is determined from the in service requirements of the deck and on the other hand a foundation of micropiles, which have the ability to contribute to the foundation's flexibility. The proposed configuration of the abutment has a number of explicit advantages compared to the currently implemented abutment design solutions as far as the homogeneity and the explicitness of the dynamic system concerns as also the maximal development of the damping capacity of the approach fill. The necessary rotational flexibility is provided through the flexibility of the thin abutment's web, which receives the vertical gravity loads of the superstructure. Appropriate measures against ratcheting effect were considered. The proposed configuration of the abutment is possible to be implemented also in long integral bridges as the required flexibility is possible to be adjusted through the micropiles foundation and the thickness of the abutment's web. For the analysis of such a non-linear unilateral behaviour of the backfill non-linear dynamic time history analysis is implemented with the FE code SAP2000.

## EFFECT OF LIQUEFACTION ON THE SEISMIC PERFORMANCE OF MULTI-SPAN SIMPLY SUPPORTED BRIDGES – ID 1379

*R. Desroches, Georgia Tech, United States*
*L. Duenas-Osorio, Georgia Tech, United States*

The multi-span simply supported bridges are one of the most common bridge types found in the central and eastern part of the United States. These bridges have several vulnerabilities which often results in less than adequate performance during earthquakes. In assessing the vulnerability of these bridges, the effect of large permanent ground displacements and liquefaction are often neglected. This is particularly a problem, since many of these bridges are located in coastal areas, where the liquefaction potential is high. This study evaluates the effect of liquefaction on the seismic performance of typical multi-span simply supported bridges. A three dimensional nonlinear models is used to perform nonlinear time history analysis, while liquefaction is accounted for by using both advanced methods and more simple techniques. The parameters that affect the seismic performance of the bridge subject to liquefaction are identified, and recommendations for modeling the effects of liquefaction are made.

## PERFORMANCE OF BRIDGES AND TRANSPORTATION NETWORKS DURING HURRICANE KATRINA – ID 1381

*R. Desroches, Georgia Tech, United States*
*J. Padgett, Georgia Tech, United States*
*B. Nielson, Clemson University, United States*
*O. S. Kwon, University of Illinois, United States*

Over forty bridges sustained moderate-to-major damage due to the storm surges, high winds, and flooding that resulted from hurricane Katrina in the southeastern United States. Most damaged bridges were adjacent to water, with the majority of the damage primarily occurring to the superstructure. Typical superstructure damage included unseating or drifting of decks and failure of guardrails due to storm surge. It was observed that the superstructure damage largely depended upon the connection type

between decks and bents. Along the coastal area where storm surge was severe, many roads were heavily damaged and/or had significant deposits of debris, further hindering traffic and recovery efforts for several weeks. Also, many moveable bridges sustained damage to their electrical and mechanical systems. The damaged observed in bridges and the impact it had on the disruption to the transportation network showed many similarities to that observed in past earthquake events. This paper summarizes the damage, discusses the impact of the damage on the transportation network in the southeastern US, and highlights the potential for designing bridge structures for both earthquake loads as well as hurricane forces.

### PUENTE BICENTENARIO DE CHILOE' - LONG SPAN SUSPENSION BRIDGE WITH STRONG SEISMIC ACTIONS – ID 1447

*J. M. Tourtois, VINCI Construction Grand Projects, France*
*P. Gernigon, VINCI Construction Grand Projects, France*
*M. Dr. Empelmann, HOCHTIEF Construction AG, Germany*
*H. W. Dr. Dorgarten, HOCHTIEF Construction AG, Germany*

Presently the preconstruction phase of the Puente Bicentenario Chiloé is carried out by the CPC Joint Venture consisting of the companies HOCHTIEF Construction (Germany), VINCI Construction Grand Projects (France), American Bridge (United States), Besalco (Chile) and Tecsa (Chile).

The project consists of a long-span suspension bridge and around 14km of roadways connecting the Chiloe Island to the Mainland of Chile.

The long-span suspension bridge with a total length of 2634m is the main structure of this project and the longest bridge in South-America. It crosses the Chacao Channel at its narrowest point with a width of 2.5km and a water depth of up to 100m. Almost in the middle of channel an underwater cliff is located, named Roca Remolinos, which is used as the foundation support of the central pylon leading to a two span suspension bridge with main span lengths of about 1100m.

The environmental conditions of this site are very severe. Strong winds and strong currents occur, which rule the design and the construction of the main bridge. However, the most important action is the high seismicity in this region, which resulted 1960 in the worldwide largest earthquake ever recorded, the Great Valdivia Earthquake with a magnitude of Mw=9.5 and the epicentre around 100km apart from the bridge site.

During the preliminary studies various seismic sources were considered such as an inter-plate fault rupture (subduction and far field event) and an intro-plate fault rupture (shallow crustal earthquakes). During the present preconstruction phase the seismic actions were further investigated and complemented, subsequently leading to a more precise detailing of the seismic design parameters. This includes the generation of seismic response spectra and artificial acceleration time histories as well as fault rupture movements of the "Gulf of Ancud Fault" potentially running along the Chacao Channel directly under the bridge site.

### A SEISMIC ENERGY DISSIPATION SYSTEM FOR SHORT AND MEDIUM SPAN BRIDGES – ID 1465

*M. Jara, Universidad de Michoacan, Mexico*
*J. M. Jara, Universidad de Michoacán, Mexico*

A seismic energy dissipation system for short and medium span bridges is proposed. The system consists in the addition of vertical metallic elements with hysteretic behavior, connecting the bent cap to the superstructure, in combination with steel layered elastomeric bearings. The vertical elements supply energy dissipation and the bearings the isolation of the bridge. Three dimensional analyses assuming rigid deck behavior were conducted and the vertical elements were represented by an idealized bi-linear hysteresis curve, assuming post-elastic stiffness ratio in the range of 5 to 12 %, typical of metallic elements. The models were subjected to time history accelerations recorded in soils of different dynamic characteristics, in order to determine the applicability of the system under earthquakes of different frequency content and duration. Several bridge models were studied, considering the most common structural types of short and medium span bridges. Evaluation of the scheme was carried out by means of the performance comparison with structures without energy dissipation devices. The numerical studies showed the effectiveness of this strategy when it is applied to simple supported or continuous bridges whose resistance is provided by flexural action of the superstructure. The efficiency of the system is improved when it is applied to short and medium period structures. Based on the results, it can be affirmed that the proposed system is effective to be used for reducing the seismic response of bridges. In addition, the scheme is economic, reliable, simple, common to the engineering practice and easy to implement.

### PSEUDO-DYNAMIC TESTING OF A THREE-COLUMN BRIDGE BENT WITH SUBSTRUCTURING – ID 1484

*N. Roy, Université de Sherbrooke, Canada*
*B. Weber, Université de Sherbrooke, Canada*
*P. Paultre, Université de Sherbrooke, Canada*
*P. Proulx, Université de Sherbrooke, Canada*

This paper describes a research project on a large-scale pseudo-dynamic testing of a three-column bridge bent. The main purpose of the tests is to optimize a retrofitting methodology for bridge columns with carbon fibre reinforced polymers based on performance crtieria and to evaluate the resulting increase in earthquake resistance. The bridge bent is part of a typical regular highway bridge located in the province of Quebec. A model with a scale of 1:3 has been built in the structural laboratory of the University of Sherbrooke. Accelerograms compatible with the uniform hazard spectrum proposed for the National Building Code of Canada (NBCC2005) are used as earthquake input. The technique applied for testing is the pseudo-dynamic technique with substructuring. In this technique, only a part of a structure is tested, while the rest is modelled numerically. In this project, the columns with nonlinear behaviour are tested, while the bridge deck is modelled with linear finite elements. The two main implicit algorithms found in the literature are compared and error propagation characteristics are given analytically and numerically. Substructuring is implemented by two different processes, which communicate over TCP/IP. One process is responsible for simulating the dynamic effects of the tested part of the structure and for controlling the testing machine, while the other process simulates the linear part of the structure by a finite element model. Numerical simulations and first tests results are shown to verify the model, the algorithm and the implementation.

### USING ISOLATION FOR SEISMIC CONTROL OF CABLE-STAYED BRIDGES – ID 1498

*J. Wilson, McMaster University, Canada*
*M. Wesolowsky, McMaster University, Canada*

The particular sensitivity of cable-stayed bridges to large amplitude long-period earthquake ground motions has motivated an investigation into the effectiveness of using seismic isolation to provide additional relief from the demands of near-field ground motions. The periods of these strong ground motions can be coincident with the main long period modes of cable-stayed bridges and can cause significant structural responses. In this study, lead-rubber bearing seismic isolators were modeled for three cable-stayed bridges, and three cases of isolation were examined for each bridge. The nine isolated bridge configurations, plus three non-isolated configurations as references, were subjected to near-field earthquake ground motions using three-dimensional time history analyses. Introduction of a small amount of isolation is shown to be very beneficial in reducing seismic accelerations and forces while at the same time producing only a modest increase in the structural displacements. It was found that there is minimal additional benefit to continue to increase the amount of isolation by further lengthening the period of the structure because structural forces and accelerations reduce at a diminishing rate whereas structural displacements increase substantially. In virtually all cases the base shears in the isolated bridges were reduced by at least 50%,

and in some instances by up to 80%, compared to a non-isolated bridge. Responses associated with individual earthquake records showed large variability from one record to the next, clearly demonstrating the caution that is needed when developing a seismic isolation system for cable-stayed bridges.

### RESPONSE OF BRIDGE PIER AND NUMBER OF ARTIFICIAL TIME-HISTORIES USED FOR NON-LINEAR DYNAMIC ANALYSIS – ID 1503

*V. B. Nguyen, University of Birmingham, UK*
*A. H. C. Chan, University of Birmingham, UK*

In this paper, a number of artificial earthquake time-histories (AETH) fitting to an EC8 response spectrum were randomly generated and the average generated spectrum compares well with the EC8 spectrum. A FE smeared crack model was then used to analyse a RC bridge pier under different sets of AETH. Several techniques including Fourier analysis, normalised cumulative spectrum, energy dissipation and damage index as well as probability theory were used to quantify the structural response of the RC bridge piers for various sets of AETH. Based on these assessments and the convergence of the representative response for different sets of different numbers of AETH, a minimum representative number of time-histories are proposed for a non-linear dynamic analysis. It was found that the number of AGETH from 8 to 11 may be sufficient depending on the response confidence band widths required. Effects of several parameters of earthquake and structural characteristics such as earthquake amplitude, earthquake duration, soil condition, viscous damping, pier height, the existence of axial load and the amount of steel reinforcement to the response and damage of the bridge pier were also investigated in a parametric study. Similar results have been obtained using the same set of AETH but, this is also true when completely different sets of AETH are used throughout this parametric study. The suggested minimum representative number of time-histories required was thus validated.

### QUASI-STATIC AND PSEUDO-DYNAMIC TESTING OF DAMAGE RESISTANT BRIDGE PIERS WITH HYBRID CONNECTIONS – ID 1966

*D. Marriott, University of Canterbury, New Zealand*
*A. Palermo, Technical University of Milan, Italy*
*S. Pampanin, University of Canterbury, New Zealand*

An increasing interest in the development of high-performance seismic resisting systems based on jointed ductile connections, comprising of unbonded post-tensioning techniques, has been observed in the past decade. An extension of this technology, originally proposed for Precast building systems, to bridge pier and systems has been recently proposed as a viable and promising alternative to traditional monolithic cast-in-place construction. In particular, specific interest has been given to the efficiency of the 'hybrid' solution which provides a type of 'controlled rocking' at the critical section. Unbonded post-tensioned tendons are combined with an appropriate proportion of mild steel energy dissipation, limiting deformations to a single gap opening and minimising damage and residual deformations when compared to equivalent cast-in-place solutions. As part of a comprehensive research program at the University of Canterbury, a series quasi-static and psuedo-dynamic tests on 1/3 scale cantilever bridge piers in either a post-tensioning only or a hybrid configuration, have been carried out. Both internal and external dissipation devices (tension-compression yielding) have been adopted for the hybrid solutions. Results are presented and compared with the performance of an equivalent monolithic cast-in-place specimen used as a bench mark specimen. Confirmation of the expected high-performance of the hybrid systems are given when compared to the response of the equivalent monolithic section: significant, low level of physical damage as well as negligible residual displacements are in fact observed. Further validations and refinements of simple lumped plasticity modelling approaches are also presented and discussed.

## ES 3c: Structural Engineering - Concrete
Level-1

### TECHNICAL AND ETHICAL REFLECTIONS ABOUT THE VERY CRITICAL INSTABILITY OF A CONSTRUCTION IN VARESE – ID 25

*F. Bartolozzi, Independent Researcher, Italy*

The building - subject of study in this paper - is a construction for dwelling consisted of five floors with twenty four living units and it is in Varese, Italy. This building was constructed in the first years of 1970 and it has a bearing structure in reinforced concrete. The very critical state of instability, which struck the bearing structure and which is pointed out from a general state of splitting, is the effect of unjustifiable design and operational insufficiencies. The cause of the phenomenon is put down both to the shortage of steel reinforcement and to the considerable problems of laying of the structures. A so worrying structural situation unavoidably causes ethical reflections too with respect to the human behavior and the responsabilities of the directly involved professional figures. Indeed, the design incompetence of the structure calculating man, as well as the great technical and professional superficiality of the work manager, of the building firm and of the structure tester emerge clear and incontestable. The very serious pathological state of the structures - pointed out, as already report , by a general and considerable state of splitting and confirmed by the advice of qualified technicians, in addition to the physical breaking of glass sighting states - induced the running assembly - after varied doubts, obstructionisms and other vicissitudes, including serious and arbitrary illations towards some scrupolous technicians - to find the only practicable way in cases of this sort, that of a radical cure of structural consolidation with a massive and targeted laying of carbon fibre lamina, in order to prevent the increase of an emergency state, become during the last days more worrying due, luckily, to an earthquake of modest magnitude, which was declaredly feared by the author of this study.

### SHEAR STRENGTH PREDICTION OF REINFORCED CONCRETE FRAME ELEMENTS UNDER CYCLIC LOADS – ID 51

*G. Arslan, Yildiz Technical University, Turkey*

In the design of reinforced concrete beams, especially those in earthquake-resistant structures, it is also necessary to prevent shear failure mechanisms. Particularly cyclic load effects do complicate the estimation of the concrete strength to total shear strength of a reinforced concrete structural member. Therefore, the contribution of the concrete to the shear strength depending on the magnitude of the cyclic load is neglected under some heavy conditions as it is in the ACI 318 Building Code. In this study, the proposed method is based on the strut and tie model, and the degradation coefficient is taken as the efficiency factor for the strut. The proposed method are verified by comparisons to extensive sets of experimental data from the literature, which have been obtained beams with various strengths of concrete, stirrup nominal strength, shear span to depth ratio, geometric size.

### A STUDY ON SEISMIC BEHAVIOR OF PRECAST REINFORCED CONCRETE WALLS – ID 79

*Y. J. Chiou, National Cheng Kung University, Taiwan*
*Y. W. Liou, Chia-Nan University of Pharmacy and Science, Taiwan*
*C. C. Huang, National Cheng Kung University, Taiwan*

This study investigates the seismic behavior of precast reinforced concrete walls. The parameters of connected steel cover plate, orientation of wall reinforcements, steel ratio of wall, and strength of concrete were studied. The results show that the precast shear wall can effectively increase the earthquake resistance of reinforced concrete structures. The performance of precast shear wall can be fully developed by using connected steel cover plates with two channel plates. The modified conventional reinforcement

with more steels at the corners produces better performance than the other orientations. The larger steel ratio and stronger concrete also definitely increase the earthquake resistance of structures.

### A CRITICAL ASSESSMENT OF CONFINEMENT REINFORCEMENT REQUIREMENTS OF IS 13920-1993 CODE – ID 87

*U. Sharma, National Institute of Technology, Hamirpur, India*
*P. Bhargava, Indian Institute of Technology, Roorkee, India*
*S. Kaushik, Indian Institute of Technology, Roorkee, India*

One of the ways in which most of the building codes of various countries ensure ductility in reinforced concrete columns, is by specifying the amount of transverse reinforcement in the critical hinge regions of columns. IS-13920: 1993 (Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces) is such a Code for India. In this paper the performance of IS 13920-93 with respect to confining reinforcement provisions for RCC columns under axial load and flexure has been evaluated. To achieve this, confinement reinforcement for square and circular concrete column cross sections were designed as per the requirements of the code for varying concrete compressive strengths (35-100 Mpa) and axial load levels (0.15 – 0.5). Theoretical moment curvature relations were found and curvature ductility factors were computed for all the columns. The effects of concrete compressive strength and axial load level on the ductility of columns, when provided with minimum lateral reinforcement as per IS 13920 code were investigated. It was concluded that the columns with high strength concretes and high axial load levels do not exhibit desired ductility when designed as per the code provisions. It was observed that the IS-13920 code is over conservative at low axial load levels and low concrete strengths and unsafe at high axial load levels and high concrete strengths. It is recommended that the distribution of longitudinal reinforcement and resulting tie configuration should be included as a design parameter in the code specifications and the use of high yield strength lateral confining steel ($>$ 415 Mpa) should be allowed to make up the loss in ductility of high strength concrete columns at high axial load levels.

### NON-LINEAR ANALYSIS OF RC BRIDGE PIERS UNDER EARTHQUAKES GENERATED FITTING TO EC8 SPECTRUM – ID 104

*V. B. Nguyen, University of Birmingham, UK*
*A. H. C. Chan, University of Birmingham, UK*

In this paper, results of a numerical study on the non-linear dynamic behaviour of reinforced concrete bridge piers under artificial earthquakes generated fitting to an EC8 spectrum are presented. A new smeared crack model for concrete, named Craft model, is well validated through various cases of RC structures under monotonic and cyclic loadings. It is then used for the FE modelling of the RC bridge piers under EC8 artificial earthquakes. The investigation focuses on the influence of various model parameters and main characteristics of artificial earthquakes affecting the non-linear seismic response. It has been observed that the seismic response of the RC bridge piers is dependent significantly on the parameters of the FE model and the properties of the artificial earthquakes. Some comments are also made to the use of the new model under cyclic and earthquake loadings.

### SEISMIC EVALUATION AND RETROFITTING OF AN OLD CONCRETE BUILDING – ID 118

*F. Danesh, K.N.Toosi University, Iran (Islamic Republic Of)*
*M. Sarafraz, K.N.Toosi University, Iran (Islamic Republic Of)*

In recent years, the subject Seismic Evaluation and vulnerability of existing buildings, that have been designed based on old seismic design codes or without Seismic design criteria , is very Important . In this paper evaluating approach for vulnerability of concrete buildings based on FEMA-273/356 guidelines have been discussed and an old concrete building has been evaluated in this regard . After evaluation of this structure, It was found that because of the lack of the compression reinforcement in top of the beams, end rotations and shear forces in most beam elements exceed the allowed rotation capacity of the beams. It is also shown that the axial forces in some columns were furthered than the acceptance criteria according FEMA-273/356. For retrofitting this building, the surrounding of the columns has been strengthened with steel jacket in lower storeys and also the diagonal bracing elements are used for upgrading the seismic capacity of the structure. The foundations of this building have been evaluated and clarified that there is no capacity of suffering of the forces resulted from the bracing system that is used for retrofitting of the structure. For this purpose, the foundations are designed and strengthened with micro pile system.

Keywords : Seismic Evaluation , Retrofitting , steel jacketing , Performance Level

### EXTERIOR PT AND RC SLAB-COLUMN CONNECTIONS SUBJECTED TO QUASI-STATIC CYCLIC LOADING – ID 144

*T. Kang, UCLA, United States*
*S. H. Kee, Hanyang University, Korea, Republic Of*
*S. W. Han, Hanyang University, Korea, Republic Of*
*L. H. Lee, Hanyang University, Korea, Republic Of*

In regions of high seismicity, post-tensioned (PT) flat plate systems are commonly used for a gravity force resisting system (GFRS), coupled with a lateral force resisting system (LFRS), assuming that the LFRS resists all seismic forces. For such combined systems, the GFRS should retain the ability to undergo the lateral deformations compatible to the adjoining LFRS without loss of gravity load carrying capacity. The purpose of this study is to evaluate hysteretic behavior of exterior post-tensioned slab-column connections (PT connections) designed to resist only gravity loads. For this purpose, experimental studies were conducted using three approximately two-thirds scaled test specimens; two exterior PT connection specimens having different tendon layouts and one exterior reinforced concrete flat plate slab-column connection (RC connection) specimen. Quasi-static cyclic loading was applied to the specimen with a constant gravity load. All specimens had bottom bonded reinforcement around the column according to ACI 318-05 and ACI 352.1R-89. This study collected previous test results to draw a general conclusion for the hysteretic behavior of the PT exterior connections. This study observed that the tendon-layout influenced the hysteretic behavior of PT connections, which means that lateral drift capacity, dissipated energy, failure mechanism, and ductility vary with respect to tendon layouts. Moreover, this study shows that the amount of bottom reinforcement specified by the ACI 352.1R-89 is sufficient for resisting positive moments resulting from moment reversal under the cyclic loading. Shear strength of the test specimens is more accurately predicted by the shear strength equation considering average compressive strength (fpc) due to post-tensioning tendons than that without considering fpc.

### EFFECT OF SEMIRIGID JOINTS ON SEISMIC PERFORMANCE OF RC FRAMED STRUCTURES – ID 193

*B. Shah, The Maharaja Sayajirao Univ. of Baroda, India*
*S. C. Patodi, The Maharaja Sayajirao University of Baroda, India*
*N. Shah, The Maharaja Sayajirao University of Baroda, India*

An RC plane frame is analysed for a single bay single storey to single bay 8 storey. Thus eight models of plane frame were studied. The frame was subjected to seismic forces and the moment at the left corner of the beam at every story was noted down for variation in the stiffness from very low (hinge condition) to very high (fully rigid condition). It was observed that for multy storied frames, the moment at the end of the beams in lower stories increased, monotonically as the rigidity increased from very low to very high. But the beam moment at the end for top story increased beyond the value of moment observed for fully rigid state, showed a peak value of moment and gradually reduced to that observed for a fully rigid state and became steady with the variation in the rigidity of the beam joint from hinge state to rigid state. This peak value

of moment is observed as 1.12 times that of fully rigid moment for a two story frame to 2.46 times the fully rigid moment for an 8 story frame. The value of beam stiffness was noted for these peak values of moments and a push over analysis was performed for the frames with beam column joint with semi rigidity introduced in the beam. The result of the performance point for frames with semi rigid joints was compared with frames having fully rigid joints. It was concluded that for frames having 3 stories and above, the seismic performance of frames with semi rigid joints deteriorates as compared to frames with fully rigid joints. For frames having less than three stories, the seismic performance is hardly affected. A similar observation is drawn for two bay frames with stories varying from 1 to 8 and stiffness of beam varying from very low to very high.

## CIRCULAR AND RECTANGULAR REINFORCED CONCRETE COLUMNS JACKETED WITH CFRP SHEETS – ID 249

*A. Ilki, Istanbul Technical University, Turkey*
*E. Karamuk, Istanbul Technical University, Turkey*
*O. Peker, Istanbul Technical University, Turkey*
*C. Demir, Istanbul Technical University, Turkey*
*N. Kumbasar, Istanbul Technical University, Turkey*

In this study, 21 reinforced concrete columns with adequate and inadequate transverse reinforcement were tested under uniaxial compression after being jacketed externally with carbon fiber reinforced polymer (CFRP) sheets. Thickness of the CFRP layer, cross-section shapes, unconfined concrete strength and spacing of internal transverse bars were the main test parameters of this experimental work. Most of the specimens were tested under monotonic increasing axial strains, while 2 specimens were tested under cyclic axial loads. The test results showed that, external confinement of columns with CFRP sheets resulted with an increase in ultimate strength and ductility. While the strength enhancement was more pronounced for the specimens with circular cross-section, specimens with square and rectangular cross-sections exhibited larger ultimate axial deformations without a substantial loss in strength. Although original specimens without adequate internal transverse reinforcement experienced premature buckling of the longitudinal bars, this phenomena was delayed significantly after CFRP sheet jacketing. Since the transverse stress provided by the external CFRP jackets was much higher than that of internal transverse reinforcement, the specimens jacketed with same thickness of CFRP sheets behaved similarly, independent of the amount of internal transverse reinforcement. According to the test results, CFRP jackets were more effective in the case of low concrete strength. The compressive strengths and the corresponding axial deformations of the CFRP jacketed columns were also predicted by the stress-strain model proposed by the authors before. It was seen that the predicted strength and ultimate axial deformations were in reasonable agreement with experimental data.

## RESEARCH, DEVELOPMENT AND APPLICATION OF HIGH STRENGTH CONCRETE IN MACEDONIA – ID 292

*R. Petrusevska-Apostolska, IZIIS, University Ss. Cyril and Methodius, Macedonia*
*G. Necevska-Cvetanovska, IZIIS, University Ss. Cyril and Methodius, Macedonia*

The application of advanced materials in design of modern engineering structures is being constantly increased in different parts of the world. Within the frame of this trend, high strength concrete with its improved physical-mechanical characteristics becomes optimal variant for many design problems. For its wide use in civil engineering, it is necessary to define precisely its properties and behaviour under different loading conditions and particularly under real seismic effects.

The current interest in this issue is reflected through the increasing number of research projects worldwide in the past fifteen years.

Scientific, industrial and construction companies in Macedonia have the potential to follow these new trends in structural engineering. In the period 1992-2005, they initiated and realized several projects in the field of high strength concrete. Four of these were carried out by the Institute of Earthquake Engineering and Engineering Seismology, IZIIS, Skopje, Republic of Macedonia. These were the following:

1. Development of Methodology for High Strength Concrete, (1992-1996-1998) 2. Methodology for Obtaining of High Strength Concrete and Its Application, (1998-2000) 3. Dynamic Behaviour of Elements and Structures Constructed from High Strength Materials, (2000-2003) 4. Seismic Resistance of High Strength Concrete Buildings, (2004-2006)

Within the frames of these projects, synthesis of the state-of-the art research has been made and complex laboratory-experimental-analytical investigations have been performed to contribute to: definition of the methodology for obtaining high strength concrete exclusively from domestic resources; joint behaviour of high strength concrete and steel in nonlinear range and behaviour of high strength concrete beams and columns exposed to seismic loads; analytical definition of nonlinear behaviour of high strength RC buildings exposed to real seismic effects and their seismic resistance, as well as definition of criteria and recommendations for application of these materials in seismically active regions. Selected results from these investigations will be presented in the paper.

## BEARING SHEAR WALLS WITH COFFOR SYSTEM – ID 293

*Z. Liu, Coffor, Australia*
*V. Davidovici, Coffor, France*

Shear walls are the most effective anti-seismic construction structure. The COFFOR System with two faces of rib lath strengthened by straighteners and connected by loops offers an easy method to build shear walls. In the past 10 years, several tests were performed in Switzerland, China, France, Egypt, Algeria to test compression resistance, deflexion, traction and ductility of COFFOR walls and slabs. As COFFOR is both a formwork and represents part of the structure, quality of concrete has been controlled. Summary of all tests will be presented Selected reference will be presented In seismic countries with frame structure culture, COFFOR is presently gaining ground as a current construction method. Several implementation and cultural obstacles had to be overcome. Multi story constructions since 1998 demonstrated the validity of the System and the quality of concrete

## ANALYTICAL MODELS FOR STRENGTHENING OF SQUARE RC COLUMNS WITH CFRP – ID 422

*A. Zarafshan, University of Tehran, Iran (Islamic Republic Of)*
*O. Huth, EMPA, Switzerland*
*M. Motavalli, EMPA, Switzerland*

Recent earthquakes have been left catastrophic economical damages. Evaluation of major infrastructures and buildings demonstrate that most of important structures are vulnerable to lateral seismic forces. And will need to repair or strengthening in near future. Therefore, innovative, time and cost saving rehabilitation methods for reinforced concrete structures need to be developed. One of these methods is the wrapping of RC Columns with Fiber Reinforced Polymers (FRP). This effective strengthening method has been gained acceptance over the past two decades. Numerous analytical models exist for the prediction of the load carrying behavior of confined circular concrete columns nowadays. However, columns with a rectangular or square cross section are common for structures especially bridge piers. In this paper two models are presented which have been modified for the application of square RC columns. Most important parameters as the number of wrap layers, the radius of rounded corners and the amount of transverse steel reinforcement were studied. Additionally, the models were compared with existing models and design codes. The comparison of test results found in published literatures and calculations showed good agreement.

### IAEA COORDINATED RESEARCH PROJECT ON SAFETY SIGNIFICANCE OF NEAR FIELD EARTHQUAKE – ID 442

*P. Varpasuo, FORTUM NUCLEAR SERVICES LTD, Finland*

The Fortum contribution to modelling and simulation effort of the results of the CAMUS 1 mock-up for the IAEA CRP on Safety Significance of Near Field Earthquakes is reported. The finite element model of the shear wall is described. Also the material constitutive equations, used in the analysis, are presented. The initial natural frequencies of the finite element model are developed. The time histories of the displacement and force variables of the model are developed. Moment-curvature relationships for different elevations of the model are calculated. The non-linear response spectra of the top of the model are determined for all prescribed input motions.

### ON THE EVALUATION OF THE RESISTANCE OF RC SECTIONS SUBJECTED TO AXIAL FORCE AND BIAXIAL BENDING MOMENT – ID 570

*L. Liberatore, University of Rome "La Sapienza", Italy*

According to the current seismic European code, two limit states must be considered for the safety verifications of structures, named the ultimate limit state and the damage limit state. The former involves the estimation of the design value of the action effects and of the corresponding design resistance of the element. For reinforced concrete elements the design resistance must be evaluated considering the characteristic values of material properties and the partial factors gc and gs for concrete and steel, respectively. Furthermore, for concrete, a coefficient taking account of long term effects on the compressive strength and of unfavourable effects due to the way the load is applied should be considered. The partial factor values adopted for the fundamental combination must be applied also for the seismic design so as to take into account the possible strength degradation of the materials due to the cyclic deformations. The adoption of these values and of the factor for long term effects, affects the evaluation of the bending resistance and, consequently, the cross section design. In this paper, the resistance of RC sections subjected to axial force and biaxial bending moment is evaluated, both by means of non linear analyses, which take into account the effect of the confining reinforcement and the degradation of the concrete in the post-elastic range, and in the simplified way suggested by the Eurocodes, i.e. considering a given stress-strain curve and a design value of compressive strength equal to the characteristic value reduced by means of the mentioned factors. A comparison between the resistances computed in the aforementioned ways is performed, evaluating also the influence of different parameters, such as de cross sectional dimension, the ratio between bending moment and axial force, the amount of longitudinal and transversal reinforcement.

### EXPERIMENTAL AND ANALYTICAL INVESTIGATION ON THE SEISMIC BEHAVIOR OF ECCENTRIC RC BEAM-COLUMN JOINTS – ID 585

*B. B. Canbolat, Middle East Technical University, Turkey*
*J. K. Wight, University of Michigan, United States*

Analytical studies of the seismic response of reinforced concrete moment resisting frame structures demonstrated that the predicted inelastic behavior was not accurate when the joint region was assumed to be rigid. One of the main purposes of the research program was to develop a joint model that accounts for deterioration of shear strength and stiffness within the connection region. Prior experimental data did not provide enough information on the inelastic behavior of connections to establish such a model. Therefore, an experimental study was performed focusing on the effect of eccentricity of the spandrel beam with respect to the column, beam and column section aspect ratios, and slab participation.

Three 3/4-scale exterior reinforced concrete beam-column-slab subassemblies were tested, in which the spandrel beam centerline was eccentric to the centroidal axis of the column. Lateral load was applied in two principal directions, one plane at a time, to determine the effect of prior loading on performance of the connection. Loading in the spandrel beam direction allowed a direct correlation between these three-dimensional specimens and prior testing of planar specimens without the floor system. Test results indicated that including the floor system significantly delayed the deterioration of shear stiffness and strength of eccentric connections.

Joint shear distortions contributed significantly to the total story drift for all subassemblies. Therefore, the experimental data on joint distortion was used, in conjunction with previously obtained data, to develop an analytical model of the inelastic deformations of beam-column-slab connections. Dynamic time history analyses were performed for a sample frame building with eccentric and concentric connections. It was observed that if a deformable joint model was not included in the structural model, story drifts were underestimated significantly. Results of the experimental and analytical programs are presented in this paper.

### DAMAGE ANALYSIS OF RC FRAMES BASED ON FLOOR CAPACITY CURVES – ID 666

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Tanganelli, Dipartimento di Costruzioni, Università di Firenze, Italy*

In recent years the approach to design structures in seismic areas has been undergoing a substantial evolution with the development of the so-called Performance Based Seismic Design (PBSD). In this respect, an essential event has been the preparation of the Vision 2000 document by the Structural Engineers Association of California, which has led to the definition of 'seismic performance objectives' as the 'coupling of expected performance levels with expected levels of seismic ground motion', thus extending the well-established concept of designing structures to resist minor earthquakes with no damage, moderate earthquakes with no structural damage and severe earthquakes without collapse. A major challenge in PBSD is to develop simple, yet accurate methods for estimating seismic demand on structures considering their inelastic behaviour and the use of nonlinear static procedures, or pushover analyses, represents a relatively simple and efficient tool. When performing pushover analysis, a key problem is to define structural collapse, which is usually related to attainment of threshold values of interstorey drift. In this paper, results from pushover analysis on a four storey RC building designed according to Eurocodes are analyzed in order to obtain information about the damage state of the structure. Namely, in addition to the usual base shear vs. top storey displacement relationship, the floor shear vs. interstorey drift relationship is determined for all floor levels. Variations in trend of these floor capacity curves give an insight into damage distribution within the structure, as well as into attainment of collapse. Also, a correspondence with target displacements obtained with different versions of capacity spectrum method is carried out.

### SIGNIFICANCE OF SHEAR MODELING ON SEISMIC ASSESSMENT OF RC STRUCTURES – ID 674

*A. Mwafy, MAE Centre, Univ. of Illinois at Urbana-Champaign, United States*
*A. Elnashai, MAE Centre, Univ. of Illinois at Urbana-Champaign, United States*

Shear failure of RC structures involves rapid strength degradation and significant loss of energy dissipation capacity. It is thus necessary to inhibit this mode of failure by insuring that the shear supply exceeds the capacity corresponding to the maximum feasible flexural strength. A versatile algorithm is therefore developed in the current study and implemented in a general nonlinear dynamic analysis program to allow for the prediction of shear failure in structural member. The shear demand-supply situation is monitored through employing two shear strength modeling approaches. The first is based on extensive experiments

and proved its capabilities in representing the reduction of shear supply with the degradation in concrete strength. Models adopted by design codes are also implemented after eliminating their conservative safety factors. The analytical models are implemented in a time-step fashion to allow for shear-axial interaction and to take into consideration the instantaneous level of ductility during the analysis. The investigated structures were realistically designed and detailed to different PGA and ductility levels to represent a wide range of contemporary buildings with variations in longitudinal (flexure dominated) and transverse (shear and confinement dominated) reinforcement. A series of inelastic response history analyses is conducted using a distinct range of earthquake records scaled to increasing earthquake intensities. The significance of including shear as a failure criterion in seismic assessment is confirmed in this study. Variations of axial forces lead to high fluctuation in shear supply and decrease the contribution of the compression strut component. The enhanced response of structural members designed to the code provisions imposed to improve ductility and shear strength in critical regions is confirmed. The shear failure is the controlling limit state in buildings designed to the minimal ductility level. This suggests improvements in the design provisions, particularly those related to maximum hoop spacing in beam critical regions.

### ANISOTROPIC DAMAGE FOR REINFORCED CONCRETE WITHIN MULTIFIBRE FINITE ELEMENT BEAM THEORY – ID 679

*F. Ragueneau, LMT-Cachan, France*
*A. Souid, LMT-Cachan, France*
*A. Delaplace, LMT-Cachan, France*
*R. Desmorat, LMT-Cachan, France*

For structures large scale computations in Civil Engineering, pragmatism at the global level has to be targeted when some physical local phenomenon have to be described. An intermediate structural descritization (between complete 3D approach and macro-element method) makes use of the multifibre theory. It allows for simple, robust and efficient computations at the global level by introducing a low number of degrees of freedom and insuring global convergence in the fastest way. The choice of using multifibre finite element configuration combines the advantage of using beam-type finite elements with the simplicity of local uniaxial behavior. The kinematics hypothesis used in the present work assumes no distorsion nor warping of a cross section.

Concerning the concrete constitutive equations, a refined modelling within the earthquake engineering scope should account for decrease in material stiffness as the microcracks open, stiffness recovery as crack closure occurs, inelastic strains concomitant to damage and induced anisotropy. The latter is obtained by an anisotropic damage model based on Continuum Damage Mechanics. The model is written within the thermodynamics framework and introduces only one damage variable 2nd order tensor. To describe the damage evolution, a damage criterion of Mazars type is used. It introduces an equivalent strain computed from the positive part of the strain tensor. The numerical scheme used for the implementation in a F.E. code is implicit, with all the advantages of robustness and stability. However, the constitutive equations of the anisotropic damage can be solved in an exact way on a time integration step. The calculation of the damage and of the stress is then completely explicit from a programming point of view. Numerical simulations of reinforced concrete structures subject to earthquake are presented in order to show the capabilities of the proposed model.

Keywords : multifibre beam, damage, concrete, induced anisotropy.

### SEISMIC PERFORMANCE OF CIRCULARLY CONFINED HIGH-STRENGTH CONCRETE COLUMNS – ID 712

*Y. Sun, Kyushu University, Japan*
*H. Matsuo, Hazama Gumi Ltd., Japan*
*J. Ishihara, Kyushu University, Japan*

Four circular concrete columns were tested under combined cyclic reversed lateral force and constant axial load to study seismic capacity of the concrete columns made of high-strength materials. Test specimens were made of concrete with compressive strength of 80MPa, and reinforced by high-strength deformed rebars having 900MPa-yield strength. To assure sufficient ductility to the high-strength concrete, circular steel tube having two thickness were used to confined the columns.

Test results have indicated that confinement by circular steel tube could ensure ductile seismic performance to high-strength concrete columns under high axial compression in the following three aspects. 1)confinement by steel tube could not only increase ductility, but also lead to increase in ultimate load-carrying capacity, since the steel tube can contain the whole column section and prevent spalling-off of the cover concrete. 2)thin circular steel tube with diameter-to-thickness ratio of 110 could provide enough confinement effect to the concrete column. 3)utilization of high-strength rebar could not only enhance the deformation capacity, but also reduce the residual deformation of the column significantly, which is a noteworthy characteristic of the high-strength column from the viewpoint of repairing of structures after the severe earthquake.

Parallel the experimental study, an analytical method was also present to simulate the cyclic performance of high-strength circular confined concrete columns. the proposed method can take both confinement effect and bond-slip effect into consideration. comparison between the measured cyclic results and the theoretical predictions has verified the validity of the proposed method.

### EFFECT OF RESTORING FORCE MODEL FOR COLUMN-TYPE RC PIERS ON DISPLACEMENT DUCTILITY BASED DESIGN – ID 737

*K. Hirao, The University of Tokushima, Japan*
*Y. Nariyuki, The University of Tokushima, Japan*
*S. Sasada, he University of Tokushima, Japan*

Objectives of this study are as follows; (1) to develop a seismic design method of a column-type RC piers based on displacement ductility (inelastic displacement demand) and (2) to discuss the effect of the difference in restoring force models (bi-linear model, some Q-hyst models) on the design result of the RC piers obtained by the proposed method. In this study, relationship among the required yield strength ratio Rr (inverse of reduction factor) and displacement ductility md , ultimate ductility mu and natural period T of the SDOF (Single Degree of Freedom) system with some different restoring force models (bi-linear model and Q-hyst models with different unloading stiffness) is obtained by inelastic response analysis for level 2 artificial earthquake motions regulated in the Japanese specification of highway bridges, provided that the value of modified Park-Ang's damage index D of the SDOF systems becomes equal to a required value, i.e., D=Dr = 0.36 (repairable limit). Regression equations of the Rr and mu are also derived as a function of the md and T. Then, by use of the derived regression equations, the authors develop a seismic design method of the column type RC piers, based on the displacement ductility (inelastic displacement demand). It is found from the design examples that the proposed method requires larger ductility of the RC piers with elastic perfectly-plastic bilinear model than that of the ultimate lateral strength method in the Japanese specification, and that the pier with smaller unloading stiffness in the Q-hyst model demands larger lateral capacity than the pier with larger stiffness, when the target response displacement ductility of the piers are the same.

### CRACK WIDTH OF REINFORCED CONCRETE COLUMNS SUBJECTED TO SEISMIC FORCE – ID 746

*I. Kishimoto, Osaka University, Japan*
*Y. Ohno, Osaka University, Japan*

In many stage and all over the world environmental issue has become serious and this situation forces us to give long life to the buildings. To give long life to concrete buildings in seismic area repairing of the members is indispensable. In the point of view of repairing buildings subjected to an earthquake disaster it is quite important to estimate the damage degree. As a standards to estimate the damage level of the reinforced concrete buildings

the measurement of crack width occur on the members is useful and rational. In the past studies on the crack width of reinforced concrete member the principal objective was to evaluate the relationship between the width of crack and stationary load. In this studies we research the crack width in plastic hinge area of concrete columns under shear force and bending moment on the assumption of the earthquake force. Five column specimens with various type of transverse reinforcement, axial load, and were tested and by using a high performance digital camera detailed falling process of concrete columns were recorded. Using those recording digital data we made clarify the mechanism of the falling process in the plastic hinge area of the concrete member and the equation which calculate the crack width related to the rotation angle of the member was developed.

### DYNAMIC RESPONSE OF REINFORCED CONCRETE STRUCTURES WITH LARGE DOMES – ID 821

*J. A. Abdalla, American University of Sharjah, United Arab Emirates*
*A. S. Mohammed, American University of Sharjah, United Arab Emirates*

The United Arab Emirates (UAE) is adjacent to the Iranian plateau which is one of the most seismically active regions of the world. Recent seismic activities in Zagros Fault Belt and Makran Subduction Zone have been felt in the UAE. Bandar Abbas (South Iran) earthquake of November 27, 2005 of magnitude 5.9 in the Richter scale and its several after shocks sent waves that shock several tall buildings in major UAE cities including Dubai and Sharjah. This earthquake sent hundreds of thousands of rattled residence to the streets of these major cities. Large span reinforced concrete domes are type of structures that are not very common in many parts of the world. However, in the Middle East, reinforced concrete buildings with large domes of different shapes (spherical, elliptical and parabolic) are very popular, especially in modern government and university buildings of Sharjah, UAE.

Behavior of large span reinforced concrete domes under earthquake loading and the interaction between domes and the rest of the structure is not well studied. This issue did not receive much attention by the research community due to the scarcity of such structures world wide. To assess the seismic vulnerability of buildings with large domes, the dynamic behavior of domes need to be studied and their susceptibility to damage need to be evaluated.

This paper, specifically: (1) studies the relationship between reinforced concrete dome shape, thickness, span and height and its dynamic characteristics such as the fundamental period of vibration and mode shapes; (2) investigates the interaction between domes and buildings; (3) compares the dynamic response of different types of domes to different ground motion records; and (4) assesses the seismic vulnerability of reinforced concrete buildings with domes to earthquake ground motion using nonlinear dynamic time-history and nonlinear static pushover analysis procedures.

### SEISMIC BEHAVIOUR OF MULTI-STOREY BUILDINGS WITH POST TENSIONED RC WALLS – ID 876

*A. Marini, University of Brescia, Italy*
*P. Riva, University of Bergamo, Italy*
*E. Spacone, University of Chieti, Italy*

This paper investigates the seismic behaviour of structural walls with post tensioned un-bonded high strength bars which entirely or partially substitute traditional reinforcement in the critical zone. The investigation is based on Finite Element analyses. Single walls are modelled by means of force-based elements, based on the Timoshenko beam theory, implemented within the FE Code FEAP. A simple non-linear shear force-shear deformation law is used at the section level, combined with a classical fibre section for the axial and bending effects. The numerical models are validated through comparison with experimental data on the performance of a 1:1 scaled traditional shear wall enduring cyclic loadings. Static pushover as well as nonlinear seismic analyses are performed. Numerical analysis results show that walls with either post tensioned or regular reinforcement exhibit similar top drifts. The elastic behaviour of the post tensioned rebars and the observed limited damage at the base section ensures that no residual displacement occurs in the post-tensioned structure after a design seismic event. As expected, a smaller energy dissipation capacity is observed when post-tensioned bars are used. Post-tensioned walls exhibit a limited increase of the inter-storey drift at the base floor. This phenomenon, which might adversely affect non structural elements in buildings, has been studied by means of non linear analyses at the damage limit state.

### 3D PUSHOVER VERSUS NONLINEAR DYNAMIC METHOD IN ANALYZING IRREGULAR RC FRAMES – ID 880

*A. Jalali, University of Tabriz, Iran (Islamic Republic Of)*
*Y. Yasrebinia, University of Tabriz, Iran (Islamic Republic Of)*

In this research the accuracy and application of 3-Dimentional pushover method in analysis of reinforced concrete structures has been inspected. 3D- pushover method can be regarded as a simple substitute for three dimensional non-linear dynamic time history analysis. The important parameters affecting the response results by using this method are firstly direction of applied forces and secondly selection of appropriate loading pattern. In order to capture the realistic behavior of structure based on results from time history dynamic analysis the aforementioned factors must be carefully selected in 3D-pushover analysis. In this study three dimensional analysis of three moment resisting frames having irregularity in plan with medium ductility have been performed using 3D-pushover and non-linear dynamic time history method. The buildings considered have 4, 6, 8 stories with similar plan in three cases .The response results obtained from both method are, maximum lateral story displacement and maximum base shear. The response results obtained from both methods have been compared in order to assess the accuracy of 3D-pushover method. Study results show that 3D-pushover analysis is sensitive to loading pattern and its direction. Load pattern according to mode shapes and combination of mode shapes show better results when building height increases. Also results of 3D-pushover in comparison with non-linear dynamic time history analysis results are sensitive to intensity of earthquake and distance of building to causative fault. In the cases where structure is subjected to strong earthquakes the results from 3D-pushover method are low and un-conservative. Results of 3D-pushover analysis are sensitive to amount of eccentricity and amount of torsions in structure. The results show that with increasing the torsion, the response results from 3D-pushover will be lower compared to non-linear dynamic time history analysis.

### EVALUATION OF DUCTILITY FOR RC PILES SUBJECTED TO CONFINING PRESSURE IN THE GROUND – ID 978

*T. Imamura, Railway Technical Research Inst., Japan*
*Y. Murono, Railway Technical Research Inst., Japan*

In the seismic design codes for railway structures in Japan, the conventional evaluation method of deformation capacity for RC piles has been empirically developed based on a large number of alternate horizontal loading tests, which were conducted under the atmos-phere. The actual deformation capacity of RC piles, however, is expected to be larger than those obtained from the in-air experimental results, because piles embedded in the ground are subjected to a confining pressure from the subgrade. The purpose of this study is to establish the conventional evaluation method of ductility for RC piles that are subject-ed to a confining pressure from the ground reaction. Therefore the alternate loading tests of RC columns are conducted, which are supported by the imitation ground composed of coil springs. Next, the calculation method of ductility for RC piles is proposed, where the confining pressure from the subgrade reaction is converted into an equivalent confining pressure from hoop reinforcements. And then in order to demonstrate the effectiveness of the newly developed method, the above-mentioned experimental results are compared with those obtained from the numerical simulation using our proposed evaluation

method. In addition, the seismic response of railway structures is calculated using the proposed model, and the applicability of the proposed model to a design practice is also confirmed.

### EFFECTIVE SHEAR AREA OF UNIFORMLY REINFORCED CONCRETE CIRCULAR SECTIONS – ID 1047

*I. Merta, Technical University Vienna, Austria*

The shear strength of reinforced concrete members without shear reinforcement is related to the shear stress carried by concrete "effective shear area". For rectangular sections the effective shear area represents the area corresponding to effective depth. However, for circular sections the term "effective shear area" is not as readily defined. Different proposals based on experimental observations have been suggested in literature but no purely analytically derived expression is available until yet. The ACI Building Code recommends employing the product of the section's diameter and the effective depth, which is 0.8 times the diameter. Thus, the effective shear area is 1.02 times the section's gross area, which seems illogical. Based on test evidences researchers suggested to calculate the shear area as 0.8 times the section's gross area. The Eurocode 2, however, does not give any instruction for circular sections. In this work the effective shear area of circular sections has been derived purely analytically. It is defined as the area corresponding to effective depth, which in turn is taken as the distance from the extreme compression fiber to the centroid of tension reinforcement. To avoid the complexity of determining the centroid of tension bars, their discrete distribution is replaced by a continuous reinforcement ring. In the range of normally reinforced concrete the ratio of the effective shear area to gross section is expressed as a function of the neutral axis depth for different values of concrete cover. For a typical value of the neutral axis depth for circular sections, it has been observed that the effective shear area ranges between 0.6 and 0.8 times the section's gross area depending on the depth of the concrete cover. Thus, an average value of 0.7 is a reasonably accurate value for the analytical estimation of the effective shear area of uniformly reinforced circular sections.

### COST MODELLING OF FOUNDATION SYSTEMS FOR RCC MULTISTOREY BUILDINGS DESIGNED FOR SEISMIC EFFECTS – ID 1092

*V. Thiruvengadam, School of Planning and Architecture, India*
*K. I. Praseeda, School of Planning and Architecture, India*
*J. C. Wason, School of Planning and Architecture, India*

Foundation systems for multistoreyed buildings serve the purpose of transmitting the gravity loads and lateral loads due to wind and earthquake effects to the founding soil strata without shear failure and excessive settlements. Under earthquake conditions and the foundation elements are required to resist additional forces due to seismic effects.

The study aims to quantify the cost premium for achieving seismic resistance of building foundations under different seismic intensities in comparison with non-seismic conditions. The study is based on the assumption that ground and foundation failures do not occur with the proper selection and structural design of foundation system based on geotechnical investigations.

The study presents the cost modeling of shallow (spread footings and mat foundations) and Pile foundations for mediumrise buildings (2 to 10 storeys) in different seismic zones of Indian sub-continent. These seismic zones are characterized by design seismic peak ground acceleration varying from 5 to 18% of acceleration due to gravity. The allowable bearing pressure of soils considered for shallow foundations vary from 100 kN/m2 to 200 kN/m2.

The proposed cost modeling of the foundation system provides the total as well as component wise bill of quantities for structural concrete, steel reinforcement, shuttering materials and the corresponding construction costs per unit floor area of the buildings considered. The parametric influence of the different seismic intensities and allowable bearing pressure of soils are brought out along with the cost premium for seismic resistance. For pile foundations, the increase in number of piles and increase in quantum of reinforcement for resisting the earthquake loads are considered. The study compliments the earlier research on the cost modeling of super structure systems.

The study is useful for foundation design practices and to carryout the cost analysis for the economic evaluation of design alternatives incorporating the costs for seismic resistance.

### INVESTIGATION ON SEISMIC PERFORMANCES OF RC FRAMES WITH REFINED MULTI-COMPONENT MODELLING – ID 1135

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Tanganelli, Dipartimento di Costruzioni, Università di Firenze, Italy*

Seismic performances of RC frame structures can be evaluated using very refined and complex local models or simplified global models. The limitation of the simplified global models is their inability to simulate the local behaviour of critical regions and yield accurate estimates of strain and curvature ductilities. On the other hand, the high computational cost associated with refined finite element models is a clear impediment in their use in large dynamic simulations. The seismic performance analyses presented in this paper are conducted with an intermediate model that can be utilized with some success for, both, global response studies of high-rise RC frames and local response studies of structural elements. The model is based on the decomposition of a frame member into different subelements. Each subelement describes a different deformation mechanism that affects the hysteretic behaviour of critical regions in girders and columns. Such an intermediate model can be really suitable for carrying out Performance Based Seismic Design (PBSD) procedures in a reliable manner. In particular, one of the main feature of this multi-component model is its ability to include in the simulations joint flexibility due to bar pull-out at the beam-column and column-foundation interface. Herein, effects of such enhanced modelling are evaluated in a PBSD format by comparing the predictions of interstorey drifts and plastic rotations with the limits provided by FEMA 356. The performance analyses are conducted on a three bay four story RC frame designed according to Eurocode 8 and subjected to the suite of 20 accelerograms generated within the SAC Steel Project for the Los Angeles area, having a probability of exceedance of 10% in 50 years. The obtained results demonstrate that inclusion of bar pull-out influences significantly the two considered response parameters, i.e. interstorey drifts and plastic rotations, regarding both values and distribution throughout frame members.

### NEURAL NETWORK ESTIMATION OF LATERAL CONFINEMENT COEFFICIENT FOR R/C RECTANGULAR COLUMNS – ID 1159

*S. Noyan Alacali, Yildiz Technical University, Turkey*
*B. Akbas, Gebze Institute of Technology, Turkey*
*B. Doran, Yildiz Technical University, Turkey*

Neural networks (NNs) are simple mathematical structures and suitable tools in establishing a reliable relationship among the various parameters. There are no complex mathematical formulations needed to design a NN. They gather knowledge by learning from examples. The results of NN yield a more realistic and accurate predictions. The design of a NN is based on simulating the structure and learning activities of the human brain. NN applications in civil engineering date back to the late eighties. Recent research demonstrated the potential use of this technique in structural engineering. The principal aim of this study is to develop and test multi-layered feedforward NNs trained with the back-propagation algorithm to model the non-linear relationship for the lateral confinement coefficient (LCC) of R/C rectangular columns subjected to axial loads. For this purpose, previous experimental studies are used to determine the LCCs of 65 columns with various geometrical and mechanical parameters. Finally, the predictions of the LCCs from both the NN analyses and the

empirical relationships proposed in the literature are compared with the experimental results. The approach adapted in this study was shown to be capable of providing the best accurate estimates of LCC by using the selected design parameters in this study. The results are considered to be encouraging for further research of expanded data sets. By setting up some random variations in the design parameters, it is possible to estimate the lateral confinement coefficient for R/C rectangular columns subjected to axial loads. The results were also tested through another NN application and similar results were obtained.

### PROBABILISTICALLY CONTROLLED DESIGN VALUES OF THE GLOBAL AND LOCAL DYNAMIC RESPONSE OF RC STRUCTURES – ID 1177

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Mezzi, Dip. di Ingegneria Civile, Università di Perugia, Italy*

The use of nonlinear dynamic analysis is spreading in earthquake resistant design of structures. Both the global and local nonlinear seismic response of r/c structures are characterized by a large scattering of the results, even when spectrum-fitting generated accelerograms are used. Several methods for estimating a conservative design value of the seismic response of an EP structure have been proposed. In some of them the design value is calculated using accelerograms selected on the basis of the geoseismic characteristics of the excitation expected at the site or its effects on the structure. These methods require, however, an accurate characterization of the site-specific earthquake, which is often not easily obtainable. In the methods provided by current standard codes, the design value is instead computed from the responses to a certain number of spectrum-fitting generated accelerograms. In some cases the number is limited to three, assuming as design value the maximum of the three responses, while recent guidelines require a larger number of accelerograms and assume as design value the average response. Both provisions do not allow to define a "characteristic" design value with a predefined probability of not being exceeded by any response. A more effective probabilistic approach is presented herein. It allows the analyst to calculate a design value of the seismic response of an r/c structure characterized by a predefined non-exceedance probability using a limited number of generated accelerograms. The estimates obtained as mean of the responses of nonlinear SDOF systems to a limited number of spectrum-fitting generated accelerograms are modified using an amplification factor defined so that the non-exceedance probability of the response estimates can be controlled. The applicability of the proposed method is demonstrated in the case of an r/c frame and the results are compared with those obtained applying current EC8 recommendations.

### DESIGN EQUATIONS FOR THE TRANSVERSE REINFORCEMENT FOR CONFINEMENT OF ELLIPTIC RC COLUMN SECTIONS – ID 1197

*J. E. Martinez-Rueda, University of Brighton, UK*
*C. Dymiotis-Wellington, City University, UK*

Recently, the use of RC elliptic column sections has received the attention of a number of researchers, both for the design of new columns and for the seismic upgrading of existing columns. In fact, because it favours the adoption of transverse reinforcement with a smooth curved trajectory, an elliptic section for a RC column is a practical and efficient option to provide the section core with adequate confinement. Although, the procedure to derive a design equation for circular spirals is well documented in the literature, the design of either elliptic spiral reinforcement or elliptic hoops for confinement has not received explicit attention. A design equation to express one of the criteria to set the required minimum content of transverse reinforcement for confinement of elliptic sections at plastic hinge regions is a practical tool for the seismic design of new columns and RC jackets. Accordingly, this paper deals with the derivation of design equations for the transverse reinforcement required for confinement of RC elliptic columns. The proposed equations comply with the principle of axial strength recovery by core confinement once the concrete cover is lost. Analytical expressions to estimate the variation of confining stresses along the main axes of elliptic sections are also introduced. The proposed design equations have the ability to include in a single model both circular and elliptic sections. On the other hand, it is also shown that the use of an equivalent circular section to simplify the design of an elliptic transverse reinforcement is both questionable and inefficient.

### SEISMIC BEHAVIOUR OF OLD CONCRETE – ID 1244

*V. Levtchitch, Frederick Institute of Technology, Cyprus*
*V. Kvasha, National University-Lvivska Polytechnica, Ukraine*
*H. Boussalis, California State University, United States*
*A. Chassiakos, California State University, United States*

The aim of this study is to obtain, expand and verify some data needed for the performance analysis of existing reinforced concrete structures. Static, dynamic and low cycle fatigue testing of 23-27 years old concrete has been carried out. Cylindrical core samples have been drilled from residential buildings in Nicosia, Cyprus. New concrete of identical composition has been prepared and tested at 28 days. Assessment of compressive and tensile strength, modulus of elasticity, stress-strain relationship, plastic strain capacity, dynamic strengthening and low cycle fatigue behaviour have been considered. Static compressive strength increase was found to be 3-15%, which is substantially lower than commonly anticipated values. There was practically no increase of static splitting strength. Elastic modulus increase was considerably larger (25%-35%) than that of strength. Up to the stress of 75% of a peak value concrete remained elastic. Dynamic strengthening was 2-4 times lower than that of 28 day concrete. Dynamic strengthening in splitting was 2-3 times lower than that in compression. Ultimate strains were 40%-50% smaller than those of young concrete. A few initial cyclic loadings bring rapid changes and the effect of dynamic strengthening is fast disappearing. At 200 cycles of loading the fatigue limit is 0.8 of the static strength. So, the large seismic strengthening commonly used in analysis is in conflict with the real phenomenon. Tensile-compressive strength ratio is dramatically decreasing. A contribution of concrete in resisting shear and torsion and the effectiveness of confinement are all diminishing. The ignoring of concrete age can result in a dramatic overestimation of its seismic capacities. Proposals for the evaluation of dynamic strengthening, low cycle fatigue limit, modulus of elasticity and ultimate strains have been formulated.

### FLEXURE-SHEAR BEHAVIOR AND DISPLACEMENT-BASED SHEAR CAPACITY MODELS FOR BRIDGE COLUMNS – ID 1255

*J. H. Lee, Yeungnam University, Korea, Republic Of*
*S. H. Ko, Yeungnam University, Korea, Republic Of*
*J. H. Choi, Yeungnam University, Korea, Republic Of*
*Y. S. Chung, Chungang University, Korea, Republic Of*

Most design codes for structural concrete such as Eurocode-2 and ACI 318 describe shear strength equations for reinforced concrete elements due to adoption of force-based design concept. Even for shear related action, however, displacement-based design concept might be more appropriate especially for seismic design. Therefore the CALTRANS Seismic Design Criteria adopts displacement-based shear model for reinforced concrete bridge column design. Reinforced concrete columns with relatively small aspect ratio show flexure-shear behavior, which is flexural behavior at initial and medium displacement stages and shear failure at final stage. Since the columns with flexure-shear failure have lower ductility than those with flexural failure, shear capacity curve models shall be applied as well as flexural capacity curve in order to determine ultimate displacement for seismic design or performance evaluation. Four full scale (diameter of 1.2 m) circular reinforced concrete columns were tested under cyclic lateral load with constant axial load. The main test variables are aspect ratio(1.825, 2.5, 4.0) and longitudinal steel ratio. Volumetric ratio of transverse hoop of all the columns is 0.0023 in the plastic hinge region. It corresponds to 24% of the minimum requirement of confining steel by the Korean

Bridge Design Specifications, which represent existing columns not designed by the current seismic design specifications or designed by limited ductility design concept. Four displacement-based shear capacity models such as CALTRANS model, Aschheim et al.'s model, Priestley et al.'s model, and Lee et al.'s model are applied to the test results and the accuracy of each model is discussed. Failure behavior and seismic performance are also investigated and discussed in this paper.

### DUCTILE CAPACITY OF RC BEAM-COLUMN ASSEMBLIES SUBJECTED TO REVERSED CYCLIC LOADING – ID 1279

*J. Y. Lee, Sungkyunkwan University, Korea, Republic Of*
*J. H. Kim, Sungkyunkwan University, Korea, Republic Of*
*H. J. Hwang, Sungkyunkwan University, Korea, Republic Of*
*M. S. Chang, Sungkyunkwan University, Korea, Republic Of*

The usual earthquake resistant design philosophy of ductile frame buildings allows the beams to form plastic hinges adjacent to beam-column connections. In order to carry out this design philosophy, the ultimate strength of the beam-column joints should be greater than the flexural yielding force of the beam and should not degrade before the beam reaches its required ductility. After the plastic hinges occur at both ends of the beams, the longitudinal axial strain at the center of the beam section in the plastic hinge region abruptly increases because the neutral axis continues to move upward toward the extreme compressive fiber and the residual strain of the longitudinal bars continues to increase with each cycle of inelastic loading. An increase in the axial strain of the beam section after flexural yielding widens the cracks in the beam-column joints, thus leading to an decrease of the shear strength of the beam-column joints. This paper provides a method to predict the ductile capacity of reinforced concrete beam-column joints that fail in shear after the plastic hinges occur at both ends of the adjacent beams. The proposed method takes into account shear strength deterioration in the beam-column joints. In order to verify the shear strength and the corresponding ductility of the proposed method, six RC beam-column assembles were tested under reversed cyclic loading. Comparisons between the observed and calculated shear strengths and their corresponding ductilities of the tested assembles, showed reasonable agreement.

### RIGID AND FLEXIBLE DIAPHRAGM BEHAVIOR OF R/C STRUCTURES RELATED TO THE RIGIDITY DISTRIBUTIONS – ID 1290

*F. G. Gulay, Istanbul Technical University, Turkey*
*U. Sahbaz, Istanbul Technical University, Turkey*
*M. M. Ayranci, Istanbul Technical University, Turkey*
*A. S. Bahcecioglu, Istanbul Technical University, Turkey*

The main purpose of the study is investigating the effect of the rigidity distributions of vertical members on seismic behavior of R/C multi-story buildings with rigid or flexible diaphragms. The 3D analyses of sample buildings with different plans are performed and in- plane stresses in slabs and member forces are computed and compared with the solutions of rigid and flexible floor assumptions. The floor diaphragms are generally considered to be infinitely rigid in its own plane in the classical approach of seismic structural analysis, whereas for some irregular structures especially in cases of floor discontinuity irregularities or with large indentations, this assumption may not always be valid, for that reason, according to the most seismic codes, it should be verified. Besides, although the codes do not put any restrictions on the rigid floor assumption of regular buildings, the computations show that large differences at the internal forces may occur at some structures with shear-walls between rigid and flexible floor solutions in addition to some stress concentrations at the slab zones close to shear-walls.

The study presents the numerical results of 3D analyses of several multi-story framed and shear-walled R/C structures having regular floors or different levels of floor discontinuity irregularities. The computations are performed with two different mathematical models, rigid and flexible floor assumptions as follows: With the first idealization, the storey masses are assumed to be concentrated at the centre of mass of the storey plan of structure where the floor diaphragm is considered as infinitely rigid and with the second idealization, the storey masses are considered to be distributed at some defined points of the slabs where the floor diaphragm is considered as flexible. Internal forces are calculated in columns and shear-walls in addition to the in-plane stress distributions at the story slabs and compared.

### A MORE REALISTIC LATERAL LOAD PATTERN FOR DESIGN OF R/C BUILDINGS WITH MOMENT FRAMES AND SHEAR WALLS – ID 1463

*M. Hosseini, IIEES, Iran (Islamic Republic Of)*
*A. Khoshamadi, Islamic Azad University, Iran (Islamic Republic Of)*

It has been observed in recent studies that the distribution pattern of the lateral loads in the elevation of the building is not close enough to the linear distribution, assumed by most codes. In this research it was tried to find a more realistic distribution pattern for the seismic load in reinforced concrete (R/C) buildings having moment frames with shear walls as their lateral resisting system, by using the nonlinear time history analyses. For this purpose, 9 various R/C buildings, which have three different numbers of bays in each direction and also have three different values for their heights have been considered. At first, the buildings have been designed by the Iranian National Code for R/C Buildings (ABA). Then they have been analyzed by "nonlinear time history analysis" software by using the accelerogarms of some well-known earthquakes, all scaled to 0.35g, 0.50g, and 0.70g peak ground acceleration (PGA) values, to find out also the effect of PGA in the seismic response of buildings as well. Results show that firstly the values of natural period of the building and the shear force, calculated by the code, are not appropriate. For example, it got clear that the number of bays, which has not been considered in the code formula, is effective in the natural period of the building. Secondly, it was found out that the real lateral load pattern is quite different with the one suggested by the seismic code. Based on the numerical results a new lateral load pattern can be suggested for this kind of buildings, in the form of some story-dependent modification factors applied to the existing code formula. The effect of natural period of the building as well as its number of stories are taken into account explicitly in this new load pattern.

### NON-LINEAR ANALYSIS OF RC BRIDGE PIERS UNDER ARTIFICIAL EARTHQUAKES GENERATED ACCORDING TO EC8 – ID 1502

*V. B. Nguyen, University of Birmingham, UK*
*A. H. C. Chan, University of Birmingham, UK*

In this paper, results of a numerical study on the non-linear dynamic behaviour of reinforced concrete bridge piers under artificial earthquakes generated fitting to an EC8 spectrum are presented. A new smeared crack model for concrete, named Craft model, is well validated through various cases of RC structures under monotonic and cyclic loadings. It is then used for the FE modelling of the RC bridge piers under EC8 artificial earthquakes. The investigation focuses on the influence of various model parameters and main characteristics of artificial earthquakes affecting the non-linear seismic response. It has been observed that the seismic response of the RC bridge piers is dependent significantly on the parameters of the FE model and the properties of the artificial earthquakes. Some comments are also made to the use of the new model under cyclic and earthquake loadings.

### RESPONSE ANALYSIS OF RC STRUCTURE-FOUNDATION-SOIL SYSTEM USING FINITE ELEMENT METHOD – ID 1504

*T. Maki, Saitama University, Japan*
*H. Mutsuyoshi, Saitama University, Japan*

Seismic response of reinforced concrete structure is highly affected by the response of foundation-soil system, especially

the structure constructed on relatively soft ground. The seismic performance verification or the seismic damage assessment for such structures should include the effect of nonlinear interaction between foundation and its surrounding soil. The current design code for concrete structures, published by the Japan Society for Civil Engineers (JSCE), prescribes the seismic performance verification of RC structures based on the response analysis in time domain of the whole structural system including their supporting foundation. In this paper, the results of response analysis for the damaged RC structures in the actual earthquake occurred in Japan, were introduced based on the finite element method. Several types of input seismic motions at the engineering base layer were chosen, and the effect of the properties of seismic waves on the structural damage was investigated. In addition, the influence of finite element modeling on the detailed structural and elemental responses was examined, and the appropriate modeling for such nonlinear response analysis using finite element method was proposed.

## CONVENTIONAL STEEL TIES VERSUS FRP CASINGS AS CONFINEMENT REINFORCEMENT FOR BUILDINGS – ID 1517

*T. Ozbakkaloglu, University of Ottawa, Canada*
*M. Saatcioglu, University of Ottawa, Canada*

Fiber reinforced polymer (FRP) casings, in the form of stay-in-place formwork, provide an attractive alternative to conventional steel reinforcement for column confinement, especially for high-strength concrete (HSC) columns. FRP casings fulfill multiple functions of; i) formwork, ii) confinement reinforcement, and iii) protective shell against corrosion, weathering and chemical attacks. However, the higher cost of FRP material and concerns over fire ratings and lack of data on long term performance provide challenges to widespread use of the material for new construction. The paper presents a comparative study of the two approaches, as applied to reinforced concrete frame buildings in practice.

A 10-storey reinforced concrete frame structure was designed on the basis of current seismic design practice. The columns were designed and detailed following the seismic provisions of the ACI 318-05 Building Code, as well as a displacement based design approach. The same columns were designed following a displacement based design procedure recommended by the authors for FRP stay-in-place formwork. The FRP reinforcement consisted of perimeter casings with and without interior FRP crossties. The application of conventional and FRP reinforcement was compared from the points of view of; i) performance, ii) feasibility and constructability, and iii) economy (material and labor costs). The results indicate that FRP casings can be superior to steel hoops and ties, especially for HSC columns, providing improved performance and inelastic deformability for earthquake resistant buildings.

## DUCTILITY IMPROVEMENT OF NON-SEISMICALLY DESIGNED RC SHEAR WALL-FRAMES – ID 1533

*J. S. Kuang, Hong Kong University of Science and Technology, Hong Kong*
*A. I. Atanda, Hong Kong University of Science and Technology, Hong Kong*

This paper presents experimental studies on two large-scale two-storey reinforced concrete shear wall-frame specimens with non-seismic reinforcement detailing and limited seismic detailing under reversed cyclic loading. The primary objective of the study is to investigate the seismic behaviour and ductility enhancement of reinforced concrete shear wall-frame buildings in an environment of moderate seismicity. The inherent ductility of an ordinary RC wall-frame is experimentally established by testing the sub-wall-frame specimen, where the reinforcement detailing is consistent with that typically adopted for shear wall-frame buildings where the design code has not stipulated any requirement for seismic compliance in reinforcement details. Experimental investigation is then conducted on the other sub-wall-frame specimen for investigating the enhancement to ductile response behaviour of displacement following modifications of the reinforcement detailing technique. The modification is simple and includes (1) in the frame, reducing the spacing between the stirrups whilst maintaining the ratio of the stirrup area to spacing, the provision of double-U stirrups at the beam-column joint and the addition of inclined bars within the beam at the support region, and (2) in the shear wall, reducing the spacing between the longitudinal bars whilst maintaining the same reinforcement ratio as that in the control specimen and providing distribution bars with an inclination angle of 45°.

It is concluded that ordinary non-seismically detailed shear wall-frame structures may not withstand a moderate seismic event. The ductility of such structures can however be improved significantly with minor modifications in reinforcement detailing specifications, which do not result in radical changes in presently practiced design and detailing techniques and in a significant increase in construction cost.

## ANALYZING SEISMIC BEHAVIOR OF PERFORATED SQUAT R/C SHEAR WALLS – ID 1537

*M. Baradaran Shoraka, Sharif university, Iran (Islamic Republic Of)*
*H. Moghaddam, Sharif University, Iran (Islamic Republic Of)*

Structural walls are used extensively in low- and moderate-rise buildings to resist lateral loads induced by earthquakes. Solid walls do not contain significant openings, but perforated walls have openings that are arranged in a regular pattern. Shear walls have openings for the penetration of piping and other requirements. In new molding systems, openings are penetrated in the wall. This paper presents the results of analytical investigation on the behavior of perforated shear walls. The openings affect the structural performances of the shear wall which consist of distribution changes of stress and strain in the elements developed around the openings and variation of strength, stiffness, ductility and failure modes of the shear wall. Analytical results of squat shear walls with numerous openings based on a nonlinear finite element analysis are discussed. Parameters such as the number, local arrangement of the openings and the reinforcing method around the openings are investigated. Based on the results, perforated walls have seen to have two modes of failure. In the first mode, the spandrels formed around the holes will fail first and ductile slender columns are obtained and the ductility capacity of the wall increases. In the second mode, failure occurs in the columns formed around the holes and a brittle and abrupt failure is seen. With the help of the $\kappa\alpha$h parameter the limit of the two failures is delineated. In both failure modes, the strength and stiffness of perforated walls decreases.

Keywords: Perforated R/C Shear Walls, Strength, Ductility, Nonlinear Finite Element

## A MODELING METHOD FOR A GIRDER OF STRUCTURES WITH SEISMIC SLITS – ID 1591

*T. Ohmura, Architectural Institute of Japan, Japan*

In 2005, the construction scandals over falsified seismic safety data were occurred in Japan. Improper construction practices were also became the focus of criticism. Many buildings were not identified with on seismic slits set, which were specified to be set in the structural drawings. It became one of the problems. Many reinforced concrete buildings in Japan consist of frame structures using columns, girders, and shear walls. In case of a large earthquake, energy absorption by the girder end plastic hinges is expected. So openings on a wall decrease the wall strength and stiffness, a wall with large openings such as those for entrances and windows are not applicable to be a seismic element. Those walls work to shorten the flexible spans of the columns and girders in case of earthquakes. In the past earthquakes in Japan, those short columns caused brittle fracture and dangerous situations. This damage served as a lesson, we obtained improper openings on walls decrease the seismic performance of buildings. In Japan, a method of construction that has been applied is to separate a columns/girder from the wall by set a seismic slit between each column/girder and the wall. By separating columns/girders from the wall, the flexible span of the girder and column become wider.

The collapse mechanism of girder can be simplified and the ductility of column can be improved. In this paper, we introduce the Japan's construction method that adopts the use of seismic slits, and the modeling method for a girder of frames with seismic slits is investigated.

### INFLUENCE OF SLIP OF REINFORCEMENT BARS ON THE COLLAPSE BEHAVIOUR OF RC COLUMNS – ID 1637

*P. P. Diotallevi, DISTART - Dept. of Civil Engineering, Italy*
*L. Landi, DISTART - Dept. of Civil Engineering, Italy*

In this paper the consequences of removing the hypothesis of perfect bond on the collapse behaviour of reinforced concrete columns were investigated. Therefore an explicit formulation of the bond-slip relationship was included, and an intermediate step between the section and the member analysis was introduced. In this phase a sub-element defined by two adjacent cracks was examined. Every sub-element was divided into slices in the longitudinal direction. An iterative procedure based on the values of the reference variable (slip) at one of the cracked ends was then applied. Considering different levels of the axial load and of the other parameters which mainly affect the flexural behaviour, the ultimate curvature of the cracked section was compared with the average curvature of the sub-element. The next step was to extend the analyses to the entire member, constituted by a series of sub-elements between adjacent cracks, with the assumption of stabilized cracking. Through numerical integration, ultimate rotation and transverse displacement were determined and these results were compared with those obtained assuming perfect bond between steel and concrete. Also the slip of the steel bar along the joint interface was considered. The anchorage slip caused a concentrated rotation at the member ends, usually called fixed end rotation. At last, theoretical results obtained by this procedure have been compared with those deriving from the application of Panagiotakos and Fardis (2001) empirical formulae, obtained on the basis of a wide experimental program.

### NON-LINEAR ANALYSIS OF REINFORCED CONCRETE FRAME STRUCTURES AND ASSIGNMENT ITS RESPONSE TO SEISMIC LOAD – ID 1891

*K. Pohl, CTU in Prague, Czech Republic*
*J. Maca, CTU in Prague, Czech Republic*

The method of calculation the seismic response of building structures according to EUROCODE 8 is based on simplifying supposition. This simplification is transformation of heavy dynamic load given by seismic shake to equivalent static load by method of progression to oscillation shapes. Conversion of dynamic task to static solution is fundamental for projection design where the solution of tasks with time variable load exceed the possibilities usual in engineer practice. Next remarkable simplification of calculation the response of structure is supposition of linear material behavior. Inaccuracy flown from this simplification grows with choice of material which show apparent non-linear behavior (ferro-cement constructions) I order to take into account the dissipation capabilities of the construction in the calculation, linear analysis will be made, based on suppositional spectrum response, which is smaller than an elastic spectrum. This reduction can be achieved by implementation of ductility coefficient q. All of these significantly simplifying suppositions lead (according to the type of a construction) to inaccuracy in assignment of resultant construction response. A comparison of thus assigned structure's response calculation with a calculation based on detailed analysis of the construction can lead to a modification of the minimal number of oscillation shapes criterion considered in the calculation, as assumed in the EUROCODE 8 norm.

## ES 3d: Structural Engineering - Control
Level-1

### EARTHQUAKE ISOLATION SELF-CENTERING SYSTEM WITH SIDE RIGID LINK-RODS – ID 27

*F. Bartolozzi, Independent Researcher, Italy*

The proposed system concerns the earthquake isolation of a construction characterized by the laying of multidirectional movable bearings and of side rigid link-rods. The link-rods have a double function: 1. to unlock a construction at the beginning of an earthquake, allowing the foundation-soil complex to move horizontally with respect to the construction, which remains almost motionless during the earthquake; 2. to lock the construction at the end of an earthquake and to hold it permanently locked in the state of soil quiet. The negligible pendulous effect in the construction during an earthquake is due to the very small inclination of the sliding surface, which is present in each bearing in order to allow the spontaneous self-centering of the construction. The seismic energy in the construction is very low, if the bearings are with sliding friction (teflon); it is negligible, if the bearings are with rolling friction (steel balls). The device, which allows link-rods to unlock and lock the construction, respectively at the beginning and at the end of an earthquake, consists of: an electro-magnet, an accelerometer or a seismometer, a control electronic station, an electric circuit connected to a small generator of electric current. The cost for making the bearings and the side link-rods in this proposed system balances the highest cost of the structures in the other existing aseismic systems characterized by total absorption of seismic energy. Nevertheless, the proposed system is certainly to be preferred with respect to the aseismic systems due to the absence of the psycho-physical discomfort for the inhabitants during an earthquake.

### STRUCTURES EQUIPPED WITH ADAS AND TADAS DAMPERS AND CONVENTIONAL STRUCTURES – ID 31

*S. M. Sajjadi Alehashem, Islamic Azad University, Karaj Campus, Iran (Islamic Republic Of)*
*A. Keyhani, Shahrood University of Technology, Iran (Islamic Republic Of)*
*H. Pourmohammad, Islamic Azad University, Karaj Campus, Iran (Islamic Republic Of)*

In recent years, new systems are used in the earthquake-resisting structures. Energy dissipating devices such as Added Damping and Stiffness (ADAS) and Triangular Added Damping and Stiffness (TADAS) are among the most promising systems in the design of the new generations of earthquake-resisting buildings. In this paper, the behavior and performance as well as the economic aspects of steel structures equipped with ADAS and TADAS metallic dampers are investigated and compared with conventional earthquake-resisting steel systems such as CBF, CHEVRON and EBF systems. For this purpose, ground acceleration records of the El Centro, Hachinohe, Sanfernando, Taft and Bam earthquakes are used as the disturbing ground motion in a series of numerical simulations of a multi-story steel building. The numerical simulations were carried out by using DRAIN-2DX program and the nonlinear dynamical behavior of the different systems was compared with each other. Results show that each of the systems has some advantages in certain circumstances.

### EXPERIMENTAL STUDY OF ACCORDION METALLIC DAMPER (AMD) – ID 38

*M. Motamedi, Islamic Azad University, South Tehran Branch, Iran (Islamic Republic Of)*
*F. Nateghi-A., International Institute of Earthquake Engineering, Iran (Islamic Republic Of)*

Using energy absorber systems like metallic dampers for controlling the structures vibrations due to earthquake has been

developed during the past decades. Also there are some studies on the energy absorption of thin-walled tubes due to impact load. Thin-walled tubes have large deformation capacity and are suitable as an energy absorber in the structure in an earthquake provided that a suitable inelastic buckling mode could occur. So in the past research the accordion thin-walled tubes are introduced as the hysteretic metallic dampers. This paper deals with the study of energy dissipation in accordion thin-walled tubes and their behavior due to axial cyclic loads. For this purpose, experimental studies have been performed. Experimental studies were conducted on a series of specimens by various geometric shapes using tension and compression actuator. These studies are focused on effects of mechanical and geometric parameters of these tubes like shape, thickness, diameter, length and material type of tube on amount of energy dissipation, axial stiffness and bearing capacity. The results show that accordion thin-walled tubes poses suitable behavior for energy absorption and by choosing the correct parameters, the optimum design of this metallic damper would be derived.

### EFFECT OF APPLICATION OF DYNAMIC ABSORBERS ON THE FOOTING VIBRATIONS – ID 97

*M. Dutkiewicz, University of Technology and Agriculture, Poland*

Technological progress and need of civil engineering development in the area of dynamic excitations: seismic, para-seismic loads, cause searching methods and means of protection building objects against vibrations. Considerable attention has been paid to researches of effectiveness of structural damping devices. Passive protection of structure has wide application in civil engineering, particularly in protection of foundations. The paper presents the analysis of vibration reduction of foundation, resting on the half space, equipped with multiple mass vibration damper. The foundation is stimulated to vibrations by seismic force. A multiple passive tuned damper is used to reduce the level of vibration and the optimum design parameters of multiple tuned damper are obtained. Effectiveness of the analyzed multiple tuned damper is compared to the single tuned mass damper. The influence of the mass coefficient of the damper on the resonating curve is analyzed. The aim of this paper is also short review of protection methods of civil engineering structures against vibrations. Knowledge of the above mentioned problem can be the guideline for designing of foundations under the dynamic excitation. Proposed solutions can be the way to receive the minimum vibrations of the analyzed construction.

### OPTIMUM PARAMETERS OF VISCO-ELASTIC DAMPER FOR CONNECTING ADJACENT STRUCTURES – ID 131

*A. V. Bhaskararao, Bapatla Engineering College, India*
*R. S. Jangid, Indian Institute of Technology Bombay, India*

The dynamic behavior of two adjacent structures, modeled as single-degree-of-freedom (SDOF) structures, connected with a visco-elastic damper is investigated. In this study, explicit equations for the optimum parameters of connecting visco-elastic damper are arrived at using a numerical searching technique. The parameters to be optimized are the damping coefficient and stiffness of the damper; and the structural response quantities to be minimized are the displacements, relative to the ground and absolute accelerations under harmonic and stationary white-noise base accelerations. The governing equations of motion of the connected system are formulated and closed- form expressions of the steady state responses of connected structures are obtained. The effect of damper parameters and damping in structures on the resulting responses is investigated. It is found that the responses of structures can be significantly reduced, if connected with visco-elastic damper of appropriate parameters. Further, it is observed that the effect of damping in structures on the optimum parameters of damper is not significant and it is more important to note that these insignificant changes in the optimum parameters of damper, due to damping in structures, have negligible effect on the final resulting responses. The influence of ratio of natural frequencies and mass ratios of structures on the optimum parameters of damper and optimum responses of structures are also investigated, from which explicit equations for the optimum parameters of damper are arrived at using a numerical searching technique assuming the damping in structures is zero. It is found that the derived explicit equations for the optimum parameters of damper are yielding good results.

### FREQUENCY RESPONSE OF A SELF-CENTERING STRUCTURE WITH BI-LINEAR BEHAVIOR – ID 132

*A. V. Bhaskararao, Bapatla Engineering College, India*
*C. Christopoulos, University of Toronto, Canada*

Now-a-days, designing of earthquake resistant structures in such a way to minimize the damage to structures, in addition to preventing the loss of lives, is receiving more importance and hence, the attention of the researchers. The development of self-centering earthquake resistant structural systems is a forwarding step in this direction. In this paper, the response of a viscously damped structure with bi-linear behavior having self-centering capability is investigated under sinusoidal ground excitation. The object of the study is to determine the viscous damping required in a structure with bi-linear behavior to yield the same response that is obtained in case of a similar structure with elasto-plastic behavior. In this direction, closed-form expressions are derived for the frequency response of the structure with bi-linear behavior. The frequency response curves are plotted for different damping coefficients to study the effect of viscous damping on the response. The results show that significant reduction in frequency responses of structure can be obtained with increase of damping and more importantly with self-centering capability. Further, design charts are developed that will allow for the design of structures exhibiting a bilinear elastic response with its full self-centering property while reducing peak displacement through viscous damping.

### BUILDINGS WITH FLOOR ISOLATION SYSTEM: PRACTICALITY – ID 187

*H. Pourmohammad, IIEES, Azad University Science and Research, Karaj, Iran (Islamic Republic Of)*
*M. Ziyaeifar, IIEES, Iran (Islamic Republic Of)*
*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*

Presented floor isolation system (local isolation systems) at this paper, basically is to control response of main structure of buildings as well as reduction of floor acceleration. The structural mass as the main source of vibration absorbs the earthquake input energy in the structure, controlling the vibration of the buildings requires isolation of mass, from the main structure which consequently from the ground (such as base isolation), called mass isolation. It is clear that the main part of mass is concentrated in the floors of buildings, so a suitable approach for controlling the response is to use appropriated isolation between the floors slab and main structure of buildings (structure frames), this method is a concept of mass isolation. Using isolators for isolating story floors are designed for light weight and low lateral stiffness against earthquake input, also building with floor isolation system require so many isolators. The available seismic isolators have the lengthy processes of manufacturing result in a high price list. In this paper a new rubber seismic isolator is proposed that may solve the above problems. In this paper, construction details of this building and proposed new isolator to make applicable of these buildings are presented. Basic principles, proposal vertical stiffness and tests results of the isolator are also presented.

### PERFORMANCE BASED DESIGNING (PBD) STRUCTURES WITH MASS DAMPERS – ID 189

*V. Smirnov, Saint-Petersburg Transport University, Russian Federation*

The PBD provides for structures calculations using several levels of seismic input and appropriate limiting conditions. Generally, calculations are carried out for rare strong earthquakes

and frequent weak ones. Under strong earthquakes, impact certain damages are supposed to accumulate in constructions. The PBD of base isolated systems faces with certain difficulties in settings parameters of earthquake protection devices, depending on the structure dynamic characteristics, as the latter change during damages accumulation. Such changes have a special influence the behavior of mass tuned dampers (MTD). There are some ways, allowing to increase the MTD efficiency for all stages of the construction work down to it destruction. Among these are - multimass MTD; - heavy weight MTD, the weight is commensurable with that of the main structure or even exceeds it; - semi-active MTD with parameters, which are adjustable depending on the accumulation of structure damages. The MTD allows to adjust each damper to a certain frequency in the range where it will work. The first of the application MTD should be adjusted to the main frequency of the intact structure, and the second one should be adjusted to the main frequency of the structure with damages. The paper considers the accumulation of damages for various models describing the fragile and plastic mechanism of destruction. Using the heavy weight MTD, when a part of the protected structure can be applied as the damper mass, allows to provide stable MTD efficiency for all input levels. The calculations show that: 1. The MTD application can be effective to improve the scenario of structure damages accumulation. 2. The MTD parameters poorly depend on the accepted model of the damages accumulation insignificantly, but they strongly depend on the speed of rigidity change as the damages accumulate. The author thanks professor A.M.Uzdin for the help at performance of the work.

## FIRST RESEARCH IN ARMENIA ON THREE DIMENSIONAL SEISMIC ISOLATION SYSTEMS – ID 196

*M. Melkumyan, American University of Armenia, Armenia*

Currently the seismic isolation technology is being extensively developed in Armenia. The construction of new seismic isolated buildings or the retrofitting of existing buildings using seismic isolation technologies to date was going on mainly in the areas located far from the active faults. However, taking into account the large scale construction in different regions of Armenia, it becomes obvious that in the near future it will be moving to the areas closer to the epicenters of the past earthquakes. The possibility of construction or retrofitting of buildings in epicentral regions requires development of seismic isolation systems able to resist not only horizontal but also vertical ground motions, which are hazardous in near source zones. Therefore, new types of seismic isolation systems need to be elaborated. This research work is based on the new concept of Three Dimensional Seismic Isolation Device (3-DSID) proposed by M. Melkumyan in 2003. It is dedicated to justification of the necessity for development of 3-DSID and to investigation of the response of structures with and without 3-DSID by carrying out time history analysis using simultaneously horizontal and vertical records of the near-field ground motions. Having as a final purpose the detailed design, manufacturing and application of 3-DSID, at this stage of research the main task was to reveal the general parameters of 3-DSID. This task was accomplished by modeling of R/C structure with and without 3-DSID and carrying out the earthquake response analysis using different time histories. The vertical stiffness of 3-DSID was chosen from the condition that the frequency of the whole structure supported by 3-DSID would differ from the predominant frequencies of the U – D near-field ground motions by about 2-3 times.

## HYBRID CONTROL STRATEGY FOR SEISMIC PROTECTION OF CABLE-STAYED BRIDGE – ID 276

*B. B. Soneji, Indian Institute of Technology Bombay, India*
*R. S. Jangid, Indian Institute of Technology Bombay, India*

In this paper, the efficacy of hybrid control system for seismic protection of cable-stayed bridge is examined. The investigation is carried out on a lumped mass finite element model of the Quincy Bay-view Bridge at Illinois. Herein, hybrid control system is composed of a passive control system to reduce the earthquake-induced forces in the structure and a semi-active control system to further reduce the bridge responses, especially deck displacements. Since, base isolation has been proved as one of the most successful means of protecting structures against seismic events, here in this study; high damping rubber bearing (HDRB) is used as a passive device and magnetorheological (MR) damper is used as a semi-active device to form hybrid control system. Control algorithm based on Lyapunov stability theory is employed. The HDRB is modeled with linear spring and dashpot. To adequately represent the intrinsic nonlinear behaviour of the MR damper, two different types of dynamic models, a Bingham model, and a Bouc-Wen model are used. In order to assess the effectiveness of hybrid system, numerical simulation results of hybrid control system considering four different strong earthquake ground motions are compared with those obtained with isolation only, and isolation along with passive viscous fluid dampers. The results indicate that the hybrid system is found to be more promising than the passive systems in reducing seismic response of the cable-stayed bridge.

Keywords: Cable-stayed bridge; isolation; semi-active; hybrid control; magnetorheological damper; seismic response

## EARTHQUAKE RESPONSE CHARACTERISTICS OF ROCKING PILLAR ISOLATION SYSTEM DEVELOPED FOR MASONRY HOUSES – ID 285

*N. Funaki, Tohoku Institute of Technology, Japan*
*T. Fujita, Tohoku Institute of Technology, Japan*
*N. Hori, Tohoku University, Japan*
*N. Inoue, Tohoku University, Japan*
*S. Kawamata, Tohoku Institute of Technology, Japan*

In developed countries of seismic area, dwelling houses and apartment houses are built based on modern construction technique and maintain some level of seismic resistance. Recently, application of seismic control technique to these houses will conspicuously advance the level of safety and reliability against earthquake. In contrast, many people in developing countries have to live in traditional masonry houses of adobes, bricks and concrete blocks by technical and economical reasons. The earthquake of M6.5, which took place in Iran on December 26, 2003, totally destroyed the historical city of Bam killing forty thousand people. The disaster reminds us that it is one of the most urgent subjects of earthquake engineering to improve seismic resistance of the houses in developing countries. However, it is not easy to shift the construction of the houses to the one of modern technology but dependence on local products of masonry material will not be changed. A possible solution of avoiding collapse of the masonry houses is to implement base isolation devices to reduce input acceleration restricting responding stress within the shearing strength of the masonry walls. In this paper, new form of base isolation system suitable for masonry houses is proposed, in which rocking pillars are utilized as bearing members. The effect of the system is verified by shaking table tests of1/4 scale test specimen. Also, numerical simulation by a developed program is carried out. Vibration response characteristics of the houses built on the base isolation system are made clear by theory and experiments.

## EFFECT OF THE STRENGTH AND STIFFNESS DEGRADATION ON STRUCTURES WITH ENERGY DISSIPATING SYSTEMS – ID 391

*O. Navarro, University of Michoacan, Mexico*
*J. M. Jara, University of Michoacan, Mexico*

Passive control devices are currently used in several countries to improve the seismic response of structures and reduce damages. A parametric study directed to determine the importance of the strength and stiffness degradation in reinforced concrete structures located in soft soil sites, with metallic energy dissipation devices is carried out. Nonlinear response history analyses of equivalent single-degree-of-freedom systems representing building models of short medium and large fundamental period are summarized. Three variations of the basic model are selected, specifically: moment resisting frame, frame with energy dissipating devices and braced frame. Push-over analysis of the building models are conducted to obtain equivalent single-degree-of-freedom

systems. To quantify the importance of the strength and stiffness degradation in the response of the structures, four parameters of the hysteretic rules that denote small, medium and large degradation are selected. All structural models are subjected to seven ground motions recorded in soft soil sites of Mexico City. Results based on the analysis of damage indexes show that the strength and stiffness degradation is more relevant in structures with energy dissipating systems when the fundamental period of the model is close to the predominant period of the ground motion. It is also shown the significant contribution of the brace-energy dissipation device stiffness in the expected damage of the models.

### CHARACTERISTICS OF A NEW TYPE VARIABLE STIFFNESS DAMPER – ID 403

*T. Furuta, Bando Chemistry, Japan*

After the 1994 Northridge earthquake in the United States of America, the 1995 Hyogoken-Nanbu earthquake in Japan, the demand to seismically retrofit the old buildings increased more and more. For the popular small wooden houses in Japan, dampers are hoped to function at both small displacement against the traffic disturbance or wind load, and at large displacement against the earthquake load. A new type variable stiffness damper consisting of high damping rubber and heat hardening polyurethane rubber is proposed. Both materials have high damping properties. While the high damping rubber material has large stiffness, the heat hardening polyurethane rubber has small stiffness. Through the combination of these two different type rubber materials, a new type variable stiffness damper is produced, which would function from small displacement to middle or large displacement. The heat hardening polyurethane rubber works mainly at the small displacement, while the high damping rubber works at the middle or large displacement. The transit point can be designed flexibly. In this paper, fundamental characteristics of a proto-type specimen are reported. At both the small or large displacement range, 30 percent critical damping ratio was obtained. The initial stiffness was small and gradually increased. It increased to 30 times of the initial value finally. Both initial stiffness and final stiffness can be adjusted by using different compounding, thickness and width of the two kind rubber materials. At last, the usage of the damper is demonstrated by a simulation study being installed in a two-story house.

### SEISMIC RESPONSE OF ADJACENT STRUCTURES CONNECTED BY NONLINEAR VISCOUS DAMPERS – ID 424

*D. Lopez-Garcia, Pontificia Universidad Catolica de Chile, Chile*
*G. P. Cimellaro, University at Buffalo, United States*
*J. L. Almazan, Pontificia Universidad Catolica de Chile, Chile*

Recent analytical and experimental research efforts have shown that the seismic response of adjacent structures can be reduced simultaneously by connecting the structures to one another at floor levels with passive devices. Nonlinear viscous dampers, however, are passive devices that have not been considered in previous studies, hence there is still a question about their suitability for the "connected structures" control approach.

The objective of this study is to comprehensively examine the seismic response of a pair of multistory building structures linked by nonlinear viscous dampers. Several combinations of values of the characteristic parameters of nonlinear viscous dampers (i.e., damper coefficient "c" and velocity exponent "alpha") were considered. The equation of motion was numerically integrated using a modified Newmark-type algorithm, and the response was evaluated in terms of peak response values of interstory drift and absolute acceleration. It must be mentioned that the building models considered in this study are analytical representations of two steel structures that are being subjected to extensive shaking table tests at the ENEA MAT-QUAL laboratories in Casaccia, Italy, to evaluate the efficacy of other types of connective devices (e.g., semi-active). Hence, results obtained in this study might be used at a later time to compare the efficiency of several types of control devices.

It was found that: (a) it is possible to simultaneously reduce both response quantities in both buildings; (b) the range of values of parameter "c" for which the former conclusion applies decreases with decreasing values of parameter "alpha"; (c) the maximum level of response reduction that can be achieved using nonlinear viscous dampers is essentially equal to the maximum level of response reduction that can be attained using linear viscous dampers; and (d) in general, the optimal value of parameter "c" diminishes with decreasing values of parameter "alpha".

### PASSIVE CONTROL OF PIPING SYSTEM: ANALYTICAL STUDIES AND EXPERIMENTAL INVESTIGATIONS – ID 474

*S. V. Bakre, IIT Bombay, India*
*R. S. Jangid, IIT Bombay, India*
*G. R. Reddy, Bhabha Atomic Research Center, India*

Passive energy dissipation (PED) devices have been successfully implemented in vibrating systems to reduce structural response, primarily due to dynamic loads, but also for wind and earthquake loadings. PED technique concentrates most of the input energy into specially designed devices, rather than allowing it to develop in the primary structural elements, and thereby reducing damage in the main structure. Passive approach of energy dissipation is widely used in piping systems, over active or hybrid passive control methods, for their simplicity in design, operation and maintenance. This paper presents the observations of shake table studies on a large-scale three dimensional (3D) piping loop usually adopted in nuclear power plants and industrial units. The piping system supported on gaps and hooks and equipped with an Elasto-plastic damper, is subjected to several spectrum compatible time-histories in the three translational directions to obtain the desired responses. The responses measured are absolute accelerations and displacements. Various computational models adopted for mathematical modeling of the gaps and Elasto-plastic device are also discussed. Finally, an attempt has been made to present a simplified way of obtaining the seismic responses of the piping system using spectrum analysis, which requires equivalent linearization of the nonlinear PEDs. Analysis is performed using PiSANL – a computer programme, developed to analyze 3D piping system equipped with PED devices. PEDs are found to be very effective in reducing the seismic responses of the piping system. Moreover, the gaps and hooks are noted to be significantly affecting the frequency contents of the observed responses of the piping system. The results obtained by the proposed simplified procedure of spectrum analysis of piping system equipped with nonlinear PEDs are in close agreement with the analytical and the corresponding experimental results.

### NONLINEAR RESPONSE OF BASE-ISOLATED BUILDINGS UNDER NEAR-FAULT GROUND MOTIONS – ID 481

*F. Mazza, Dipartimento di Strutture, Università Calabria, Italy*
*A. Vulcano, Dipartimento di Strutture, Università Calabria, Italy*

The widespread application of base-isolation systems for framed buildings is encouraged by the development of suitable code provisions. Lately, also the seismic code drafted in Italy (Ordinanza P.C. 3274, OPCM) contains a chapter concerning with the seismic isolation. At present, OPCM has taken into account the effects of far-fault ground motions, considering the vertical component of the seismic load when the ratio between the value of the vertical stiffness and the analogous value of the horizontal stiffness is less than 800. Moreover, in a high risk seismic region, OPCM adopts a peak value of the vertical acceleration (PGAV) up to 0.9 of the analogous value of the horizontal acceleration (PGAH). But the near-fault ground motions are characterized by long-period horizontal pulses and values of the acceleration ratio (PGAV/PGAH) even much more than 1, which can become critical for base-isolated structures. The objective of the present work is to check the effectiveness of the base isolation of framed buildings realized by rubber (HDLR) bearings, considering the combined effects of the horizontal and vertical components of near-fault ground motions, in order to establish if suitable additional code

guidelines are needed. To this aim, a numerical investigation is carried out with reference to base-isolated five-storey reinforced concrete buildings designed according to OPCM. The design of the test structures is carried out in a high-risk region considering the horizontal seismic load, with or without the vertical one. The non linear seismic analysis of the test structures is carried out by using a step-by-step procedure, checking the plastic conditions at the potential critical sections of the girders and columns. Viscoelastic models with either constant or variable stiffness properties are considered for simulating the behaviour of a HDLR bearing in both the horizontal and vertical directions. Real and artificially generated (matching OPCM response spectra) accelerograms are considered.

### ANN CONTROL OF FRAMES FOR FUTURE EARTHQUAKES – ID 547

*M. K. Bhardwaj, IGNOU, India*
*T. K. Datta, I. I. T. Delhi, India*

An active control scheme using ANN is presented for seismic control of building frames for future earthquakes. It is based on the premise that if desired control force and future earthquake excitations have similar frequency content, it is likely that the control force of the system will be most effective. Therefore, for training neural net the desired control force is assumed to have the same nature of the power spectral density function (PSDF) as that of the ground acceleration which are modelled as stationary random process. Thus, training of neural net involves generation of time histories of ground acceleration and control force from their PSDFs. Target peak control force is related to the moments of the PSDF of control force using standard expressions. The control scheme developed has the advantage that it can consider (i) limited number of feedback measurements, (ii) time delay effect, and (iii) target reduction in response. The ANN control scheme requires feedback responses (displacement, velocity and acceleration), ground excitation and a target percentage reduction as inputs to the ANN. The output of the ANN is the time history of control force. A ten storey building frame is taken as an illustrative example. Feedback responses are taken from 1st, 5th and 10th storeys of the frame. The control is affected by a single control force applied at the top of the building frame with AMD. The results of the study show that (i) the control scheme is very effective in controlling the response of the building frame for excitations under El Centro earthquake taken as an unknown problem. (ii) The peak control force required to obtain a significant percentage reduction in response is not very large. (iii) Time delay (of the order of $2\Delta t$; $\Delta t$ time step interval) marginally deteriorates the performance of control scheme.

### EVALUATION OF DAMAGE OF STRUCTURES WITH SHAPE MEMORY ALLOY DAMPERS SUBJECTED TO SEISMIC EXCITATIONS – ID 594

*S. A. Motahari, University of Terhan, Iran (Islamic Republic Of)*
*M. Ghassemieh, University of Tehran, Iran (Islamic Republic Of)*

Employing different damping and base isolation systems for passive and active control of structures subjected to seismic excitations has been a great concern for researches in the last decade. In last few years smart materials and systems have also found their way as innovative strategies in seismic control of structures. Shape memory alloys (SMAs) as smart materials with several unique characteristics are one of the most favorable materials in this emerging field of engineering.

SMA materials exist in two crystallographic states: the parent austenite phase and the product martensite phase. SMA materials are favorable for use in seismic applications, because of their recentering capability in Austenite phase, high damping capacity in martensite phase and very high fatigue resistance in both phases.

In this paper different behaviors of SMAs in their two different states are obtained by a constitutive model previously proposed by the authors. Then it is shown that by proper combination of two states of SMAs in a damper a favorable response can be found. This special damper can strongly prevent the accumulation of residual displacements in the structure due to its dual recentering and damping capabilities.

In order to obtain a global comparison between the behavior of a structure enforced with the proposed damper with common steel frames and for obtaining a good measurement on the benefits of the use of the proposed model the idea of damage indices is used. Structural damage, non-structural damage and damage to contents of a structure subjected to real earthquake time histories are evaluated. A new idea for determining the total structural damage of the structure is also introduced in this paper. In the proposed method, the damage of structure is integrated only on the main members of the frame which are critical for the total collapse prevention of the structure.

### NUMERICAL AND EXPERIMENTAL STUDY OF HIGH DAMPING ELASTOMERS FOR ENERGY DISSIPATING DEVICES – ID 654

*P. Mata A, Technical University of Catalonia, Spain*
*R. Boroschek, University of Chile, Chile*
*A. Barbat H, Technical University of Catalonia, Spain*
*S. Oller M, Technical University of Catalonia, Spain*

Elastomers are frequently employed in construction of energy dissipating devices for controlling vibrations in structures. Their mechanical characteristics and energy dissipating capacity are strongly dependent on the composition of the mixture and on the fabrication process. In general, their mechanical behavior is complex presenting an elastic modulus, which depends on the strain level and frequency among others. The material also shows different types of energy dissipating mechanisms, which can go from purely hysteretic to viscous. Additionally, in the case of loadings imposing large strains and depending on the boundary conditions, strain hardening become noticeable.

A constitutive description for elastomers has to consider large displacements, nonlinear strain-stress relationship, incompressibility and energy dissipation. Actually, it is possible to find numerical models based on the principles of the continuous mechanics with appropriate constitutive laws for elastomers, but normally they are time consuming and the convergence of the problem is not ensured. Other models are based on fitting equations to experimental data, providing algorithms which describe the material or the whole device behavior. This possibility has the advantage of being more economic in computing time and allows calibrating the model from loading tests, although the provided model only is able to describe the behavior of the specimen or device for the conditions of tests.

The use of equivalent linear models can induce errors in the estimation of the energy dissipated by the devices because the mechanical properties of the materials are considered constants. This work presents an analytical model for dissipating devices based on elastomers. The model is able to simulate strain hardening and variable mechanical properties. The model depends on a set of parameters determined from experimental tests. The response of the new model for arbitrarily loadings is compared with experimental data and other models.

### EFFECTS OF NEAR-FAULT EARTHQUAKES ON THE NONLINEAR RESPONSE OF R.C. FRAMES WITH DISSIPATIVE BRACES – ID 672

*F. Mazza, Dipartimento di Strutture, Università Calabria, Italy*
*A. Vulcano, Dipartimento di Strutture, Università Calabria, Italy*

The insertion of dissipative braces proves to be effective in order to enhance the performance of a structure under horizontal seismic loads, but no evidence is available under vertical seismic loads. In the conventional aseismic design of framed buildings the effects due to the vertical seismic loads are assumed negligible in comparison with those due to the combination of gravity loads and horizontal seismic loads. Specifically, the seismic code introduced in Europe (Eurocode 8, EC8) does not require to consider the effects of the vertical component of the seismic action for framed buildings. However, near-fault earthquakes are characterized by long-duration horizontal pulses and values of the ratio between the

peak value of the vertical acceleration and the analogous value of the horizontal acceleration even larger than 1. High values of this acceleration ratio can modify the axial force in reinforced concrete (r.c.) columns, with high compressive forces, larger than the balanced force, and even tension. Moreover, the vertical component of motion can induce an increase of the ductility demand for the girders, especially in their central part at the upper storeys of tall buildings. To investigate about these questions, twelve-storey r.c. plane frames, representative of high-rise symmetric framed buildings, are considered. The design of the test structures is carried out considering only the horizontal seismic loads evaluated according to the provisions of EC8. For the purpose of retrofitting the test structures under vertical seismic loads, chevron or single diagonal braces equipped with viscoelastic devices (VEDs) and differently arranged in elevation are considered. A nonlinear dynamic analysis is carried out by using real and artificially generated (matching EC8 response spectra) accelerograms. The frame members and the VEDs are modelled, respectively, by a bilinear model and a six-element generalized model obtained as an in-parallel-combination of two Maxwell models and one Kelvin model.

## ON THE APPLICATION OF DYNAMIC DAMPER FOR IMPROVEMENT OF BUILDINGS SEISMIC RESISTANCE – ID 675

*M. Mnatsakanyan, YSUAC, Armenia*
*Z. Khlghatyan, NSSP RA, Armenia*

The Spitak (Armenia), 1988 destructive earthquake has shown that seismic hazard in the territory of Armenia is considerably higher than buildings and structures seismic resistance and practically the all territory is concentrated in the zone of high seismic risk. In this condition estimation of the vulnerability of buildings and structures becomes especially actually for Armenia. Before the Spitak destructive earthquake in the Republic of Armenia there were applied traditional methods of construction. There were not applied such modern methods as seismic isolation, dynamic damping model, Hysteretic damping, frictional damper and etc. In this work, first time in Armenia, by experimental method it was made an attempt to check effectiveness of dynamic damper in improving seismic resistance and reliability of building. It was established dynamic model of the 12 stored residential building by 1:15 scale. The main peculiarity of the model is that the upper floor slab is playing the role of damper. The parameters of the dynamic dampers were designed so, that it would have effect by the first vibration form. There were done corresponding dynamic model experiments. The results of the experimental researched showed that the dynamic damper in the wide zone of the external influences vibrations approximately two times decreases the displacement of the upper floor of the model. It was done seismic calculation of the model under the real earthquake. The results of calculations and experiments showed the dynamic damper effectiveness and its application fields.

## DEVELOPMENT AND TESTING OF AUTONOMOUS CONTROLLER FOR SEMI-ACTIVE CONTROL DEVICE – ID 697

*M. H. Shih, National Kaohsiung First University of Science and, Taiwan*
*W. P. Sung, National Chin-Yi Inst. of Tech., Taiwan*

In this research, autonomous controller is developed to provide the function of "Sensing-Computing-Transferring" for improvement of semi-active control device. This proposed controller has qualifications of detecting structural response under the excitation of earthquake. This controller depends on the semi-active control law to produce control order to adjust and control the action of semi-active control damper. Principle of autonomous controller is: 1.) Autonomous controller and damper-added stiffness element are parallel connection; 2.) Autonomous controller is produced the direction of pressure force and velocity moving direction of structure to change sign simultaneously by the deformation of structure; 3.) By reverse process of moving direction of structure, the action of switching direction of damper has been finished when the tiny displacement of structure is happened. In order to simulate the practical application of this proposed controller, the connection of a soft spring, damper and actuator are in serial connection. These test results reveal that the function and energy-dissipating behavior of this proposed controller is similar to traditional semi-active controller, switch status of damper at the right opportune moment. This proposed controller can replace the detector, central control computer and damping controller included in original semi-active control system. The advantages of this developed autonomous controller are: 1.) low manufactured cost; 2.) low requirement of system maintenance; 3) high reliability of control system.

Key Words: Autonomous controller, sensing-computing-transferring, semi-active control

## SEISMIC REDUCTION PERFORMANCE OF PREDICTIVE CONTROL-VELOCITY PREDICTOR FOR SEMI-ACTIVE DAMPER – ID 699

*W. P. Sung, National Chin-Yi Institution of Technology, Taiwan*
*M. H. Shih, National Kaohsiung First University of Science and, Taiwan*

The component tests of velocity predictor based on displacement signals for semi-active hydraulic damper reveal that this calculation method can promote the seismic proof effect successfully. The displacement response of structure is random with random of earthquake excitation. In order to ensure the predictive application of this calculation method, shaking table tests are used to demonstrate the feasibility of this predictive method, predicting the reverse timing of moving direction of structure properly. Shaking table tests results indicate that the seismic reduction performances of this method are: 1.) the displacement reduction effect can promote 30%-40%; 2.) the acceleration reduction effect rise to 43%. This predictive method is suitable for strong earthquake and small-scale magnitude earthquake, happened frequently, based on the analytical results of this research.

Key Words: predictive calculator, velocity predictor, shaking table test, semi-active hydraulic damper

## SINGLE MODE NONLINEAR SEISMIC CONTROL OF BUILDING FRAMES WITH ANN – ID 736

*T. K. Datta, Indian Institute of Technology Dehli, India*
*M. R. Manepalli, Indian Institute of Technology Dehli, India*

Efficient control schemes using artificial neural net (ANN) are presented for the reduction of nonlinear response of SDOF system subjected to support excitation. A feedback control scheme is adopted in which the feedback of the responses is considered as input to the neural net. Three types of controllers are developed with closed-loop and open-closed loop schemes. Application of the control scheme is restricted to building frame which has widely spaced frequencies and whose response (elastic) is predominantly governed by the first mode response. The neural nets are trained for a predetermined reduction of response, called the target reduction and for an assumed time delay between the measurement of response and the application of control force. The time delay is caused due to the computational time and implementaional time required for the generation and application of the control force respectively. The data pairs for training the neural nets are generated from responses and control forces obtained for a set of artificially generated earthquake records. These records are simulated from the double filtered power spectral density functions (PSDF). For the multi-storey frame, the control schemes developed for the SDOF system can be used for controlling the nonlinear response of the frame. Performance of ANN control schemes are tested for the El Centro earthquake data for controlling the nonlinear response of a ten storey building.

## CONTROL INSIDE OF STRUCTURAL SYSTEM : THEORY AND EXPERIMENT – ID 847

*M. Juhas, STU, Slovakia (Slovak Republic)*

*V. Svrcek, STU, Slovakia (Slovak Republic)*
*G. Bergamo, CESI, Italy*

The theory and practice of automation and control have been developed for different purposes. In this direction such approach can be also applied for the improved performance of different structures in conditions of strong seismic motion effects. The paper will present the analysis and experiments that have been executed by research teams from STU and SAS Bratislava Slovakia using facilities of former ISMES in Seriate, Italy. Two independent control systems were used for the test: the first one for the control of the shaking table and the second one for the control inside of tested specimen. Tested specimen represented two storey steel frame with different brace systems. Application of the mechatronic approach elaborated by the first author will be described in details in the paper. The results have proved the efficiency of control and the influence of different tuning procedures.

## MULTI-STOREY STRUCTURES WITH VERTICALLY DISTRIBUTED SEISMIC ISOLATION – ID 891

*M. Phocas, University of Cyprus, Cyprus*
*P. Komodromos, University of Cyprus, Cyprus*

The concept of structural systems with integrated, distributed seismic isolation at different elevations aims at the development of earthquake resistant multi-storey buildings with high performance requirements during strong earthquakes. The structural system may consist of a primary system and a tuned secondary system with multiple base isolations over the height. The complex control mechanism enables that during moderate earthquakes the secondary structure itself acts as absorber of the kinetic energy through its own displacements, which are controlled at the isolation levels, minimizing thus the displacements of the building. In addition, due to the reduction of the induced accelerations by the isolation mechanisms, the controlled subsystem maintains the functionality of the building and secures human comfort. During strong earthquakes the effectiveness of the system in further enlarging the period of the building, compared to the classical method of seismic isolation at a unique level, is achieved without introducing extensive displacements at the building base, which are often limited by practical constraints. In parametric studies, using time-history analysis, the effectiveness of the proposed control system is compared to a conventionally base isolated system, and the stiffness and damping properties of the system components (primary, secondary structure, isolation mechanisms) are investigated for a most effective tuning and earthquake resistance of the building.

## INELASTIC VIBRATION ABSORBER FOR MULTI-STOREY BUILDINGS ASYMMETRIC IN PLAN – ID 898

*B. K. Raghu Prasad, Indian Institute of Science, India*

The present study discusses the feasibility of a design approach based on 'expandable top story' for the multistory RC-buildings including torsional e®ect. If such a behavior is feasible one can conceive of a structure whose top storey is permitted and designed to undergo large inelastic deformations while reducing damage in the lower storey. The concept was first proposed in my earlier paper[43]. Such a concept juxtaposes the often-mentioned 'soft ¯rst story' concept.

## OPTIMAL DAMPER SIZING FOR DIFFERENT DAMPER PLACEMENTS IN SHEAR-TYPE STRUCTURES – ID 940

*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*

This paper illustrates the advantages offered by inserting added viscous dampers into shear-type structures in accordance with a special scheme based upon the mass proportional damping component of Rayleigh viscous damping matrices (referred to as MPD system). This system is characterised by a peculiar damper placement which sees the dampers placed so that they connect each mass to a fixed point (fixed-point placement), thus being substantially different from the usual interstorey placement. The dynamic behaviour of shear-type structures equipped with the MPD system is here compared with that of shear-type structures equipped damping systems identified as "optimal" using genetic algorithms. This identification of the "optimal" damping systems is here performed so that, under the equal "total size" constraint, (1) optimal sizing is obtained for interstorey damper placement, (2) optimal sizing is obtained for fixed-point placement, (3) optimal sizing is obtained for a system of dampers which connect floors which are no more than three storeys apart and (4) optimal sizing is obtained for free damper placement. The dynamic response of the MPD and the "genetically identified optimal" (GIO) systems (shear-type structures + added viscous dampers) to both stochastic input and selected earthquake ground motions show that the MPD system is capable of providing good overall dissipative properties. The results also indicate that numerical optimisation leads to GIO systems which are very similar to the MPD system in terms of damper placement and that the large damping capacities of the MPD and some GIO systems are mainly linked to the peculiar placement of dampers and only weakly depend on the optimal sizing.

## SMART TECHNOLOGIES FOR SEISMIC PROTECTION OF HISTORICAL STRUCTURES – ID 959

*A. Mandara, Second University of Naples, Italy*
*A. Durante, Second University of Naples, Italy*
*F. Ramundo, Second University of Naples, Italy*
*G. Spina, Second University of Naples, Italy*

The use of structural control systems for seismic protection of structures represents a relatively new area of research that is growing rapidly. A wide variety of devices is now available, ranging from simple passive dampers and isolators to complicate active systems with actuators, sensors, and digital controllers. Passive systems represent a reliable and satisfactory way to protect civil structures from seismic action used in many applications worldwide. A limit of this technique is the lack of adaptability to changes in external loading. Alternatively, active structural control systems are available, using high performance sensors and actuators digitally controlled by specific algorithm derived from optimal control theory. However, active systems are more complex and expensive, less reliable than passive systems and may require relatively large external power supplies. These factors limit their use in seismic protection applications. The aim to obtain an effective, reliable and affordable structural control system can be reached using smart devices: these are very similar to passives, but have the important difference to be controlled in real time, modifying the control forces by means of a change of their mechanical properties. Magnetorheological (MR) dampers are one of the best examples of smart devices, due to their capability to dissipate energy and their low power requirements. The aim of the paper is the evaluation of the effectiveness of a mass damping vibration control system on the seismic demand reduction in a historical building. A specific logical scheme of the building fitted with smart devices has been created by means of the Matlab Control-Toolbox. The effects coming from the devices activation have been simulated by imposing suitable control laws to related damping parameters of the model. Based on this assumption, the performance of the semi-active control system has been evaluated in comparison with the passive and active control strategy.

## DESIGN STUDIES FOR LARGE NUCLEAR PROJECTS ON ASEISMIC PADS – ID 1096

*P. Sollogoub, CEA, France*
*I. Politopoulos, CEA, France*
*X. Bravo, CEA, France*
*L. Patisson, CEA, France*

There is a large experience in using aseismic pads for Nuclear facilities in France: 900Mwe PWR units, research laboratories, storage pools... They have each more than twenty years of operating experience. Two very important nuclear projects are starting in CEA Cadarache center in south-east of France: The planned ITER facility is intended to demonstrate the viability of nuclear fusion as an energy source. It will do so by magnetically confining a Deuterium-Tritium plasma and heating it to a temperature of about 100 millions degrees. It has been an option to study the possibility to locate the core of the facility - the toroidal structure where the fusion reaction will take place, called the tokamak - in a building resting on aseismic neoprene pads. A research reactor named RJH, Réacteur Jules Horowicz, intended for R/D related to irradiated materials with the capability of testing different nuclear devices. The nuclear unit is composed of one civil engineering structure supporting two zones with different containments: the reactor building (RB) and the nuclear auxiliary building (NAB). The objective of this single structure is to contain all the radioactive materials in one place. This structure is placed on aseismic pads. The objective of the paper is to: · Present the French experience feedback about base isolated facilities · Describe the new projects and their base isolation · Describe the features of the qualification program and some relevant results · Present some special topics associated with the use of these devices

## SPECTRAL ANALYSIS OF SDF SYSTEMS EQUIPPED WITH NON-LINEAR VISCOUS DAMPERS – ID 1172

*P. P. Diotallevi, DISTART-Dept. of Civil Engineering, Italy*
*L. Landi, DISTART-Dept. of Civil Engineering, Italy*
*A. Dellavalle, DISTART-Dept. of Civil Engineering, Italy*

A simplified method of calculating the response spectrum of a SDF system equipped with Non-Linear Viscous Dampers is proposed. It is known that the response of a Non-Linear Viscous Dampers is proportional to a fractional power-law of the velocity, the exponent (a) of which ranges between 0.1 and 1. The response of these systems is usually investigated by replacing, in the equation of motion, the non-linear term related to the damper with an equivalent linear term. This linearization is obtained by equivalent energy approach or by equivalent power approach. It has been shown that these procedures are reliable for resonance conditions and exponent a values next to the unit. In order to reproduce a more reliable behavior of the system over a wider range of cases the problem has been studied by keeping the non-linearity within the equation of motion. The equation of motion has been rewritten introducing an adimensional term (nd* ) called "damper ratio", which describes the behavior of the damper. The response of the system has been calculated, numerically, for harmonic force and real accelerogramms, as function of nd*,a,T. A comparison with the response of a system not equipped with Non Linear Viscous Dampers has been made in order to evaluate a reduction factor (B).

## STUDY FOR THE EARTHQUAKE PROTECTION OF A RC FRAME BUILDING WITH ADDED VISCOELASTIC DAMPERS – ID 1173

*P. P. Diotallevi, DISTART - Dept. of Civil Engineering, Italy*
*L. Landi, DISTART - Dept. of Civil Engineering, Italy*

The paper shows the seismic upgrading of a nonductile concrete frame building with added viscoelastic dampers, which are able to provide a large dissipative capacity without requiring strong bracing systems. In the first part of the study the response of SDOF systems subjected to various excitations is investigated in order to define a reliable mathematical model for the viscoelastic dampers. In the second part of the study the model is applied for the analysis and design of an earthquake protection system for an existing RC building. The building was designed for only gravity load and is characterized by irregularities in plan and elevation. A particular design procedure is developed and applied, and a new type of viscoelastic damper is proposed. Then the effectiveness of the protection system is verified through linear response spectrum and non linear time history analyses.

## EFFECT OF PIERS' FLEXIBILITY ON THE SEISMIC RESPONSE OF ISOLATED BRIDGES – ID 1174

*S. Berton, Anteris s.r.l. societa' di ingegneria, Italy*
*M. G. Castellano, FIP industriale s.r.l., Italy*
*S. Infanti, FIP industriale s.r.l., Italy*

A large number of bridges located in active seismic regions are protected against strong earthquakes through the use of seismic isolators. These devices, due to their lateral flexibility and energy dissipation capacity are able to reduce the seismic forces transmitted to piers and foundations. Seismic isolators are usually installed between the superstructure and the support system, at the abutments and at the intermediate supports on the top of the piers. Because piers can be tall and flexible, the response of the isolated bridge and the isolation capacity of the isolators might be significantly influenced by the flexibility of the piers on the top of which they are installed. In this paper the results of a parametric study based on a series of numerical simulations of an isolated bridge model are presented. The study consists of carrying out a series of nonlinear time history analyses when the model is subjected to a set of input ground motions. The model represents a continuous simply supported two-span isolated bridge in which only one isolator is installed at the intermediate pier. The isolator is considered to possess a nonlinear response characterized by a bilinear force-displacement relation. During the simulations the parameters characterizing the model and in particular the flexibility of the pier are varied and the results compared. Particular focus is given to the influence of this parameter on the model peak deformation and on the self-centering capacity of the isolation system.

## DETERMINATION OF NON-LINEAR PARAMETER OF VISCOUS DAMPER USING OPTIMAL ALGORITHM – ID 1175

*A. Sotlany, International institute of earthquake engineering, Iran (Islamic Republic Of)*
*M. Ziafyar, International institute of earthquake engineering, Iran (Islamic Republic Of)*

Today that's very common to use systems to decrease responds of structures related to excitation. Since there are a variety of control systems each has a special design, there fore optimum designing in constructs and characters of these systems have been discussed. Regarding recent developments on viscous damper with linear and non-linear and also regarding their easy and simple installation in structures, this study is concentrated basically on designing these kinds of systems. In this way , we case optimum algorithms of active control to gain optimum characters (non-linear dampers system). Mathematic algorithms can optimize system behavior function in active control. There fore simulation of this behavior accompanying realistic models of viscous damper produces designing method of our study. In this thesis we are going to try to order to introduce and easily to make systems which can be used active or semi-active in systems. This design is so that provided tools and systems can have an output as an active system in structures. That is this instrument can optimize response on the base of favorite performance and in the best possible way. After conducting the required studies on viscous dampers with non-linear behaviors, the different non-linear function are were considered for behavior of a damper. The parameters of each function are calculated using optimum-finding algorithms in control systems. After providing behavior function of non-linear dampers their differences and advantages are considered. Also you will observe that compound hybrid systems are useful in designing of these instruments and they are easily practiced.

## SEISMIC ISOLATION OF RC STRUCTURES SUBJECTED TO NEAR-FAULT GROUND MOTIONS – ID 1201

*P. P. Diotallevi, DISTART - Dept. of civil Engineering, Italy*
*L. Landi, DISTART - Dept. of civil Engineering, Italy*

*S. Benni, DISTART - Dept. of civil Engineering, Italy*

The purpose of this work is to study the effects of near-fault ground motions on the nonlinear dynamic response of RC base-isolated structures. A numerical investigation is performed with reference to base-isolated reinforced concrete spatial frames designed according to Eurocode 8. The high damping rubber bearing (HDRB) is adopted for the isolation system. The analyses are carried out considering non-linear behaviour both for the isolation system and for the RC structure. The RC structural elements are modelled with a linear elastic element and two non linear rotational springs at the ends. For the bearings a bilinear model with strain-dependent hysteresis rules is considered. Earthquake records with typical properties of near-fault ground motions are applied to the structure under investigation considering both the horizontal and the vertical components. Then the effects of dynamic properties of the near-fault motions and the vertical component are investigated in terms of displacement and ductility of the superstructure and of deformation of the bearings.

## OPTIMAL PARAMETERS OF PASSIVE TUNED MASS DAMPER – ID 1294

*G. Hemalatha, Anna University, India*
*V. Udhayakumar, Anna University, India*
*K. P. Jaya, Anna University, India*

Tall and flexible buildings are the trend in modern day construction. The inherent damping in the structure may not be sufficient to increase the comfort level of the occupants, safety of the structure and its functionality against strong earthquake or wind loads. Unlike vibrations considered in other disciplines such as mechanical engineering, the type of disturbance a building undergoes due to an earthquake is highly non-stationary and has enormous energy that can impart fatal damage to the building and to the secondary systems. Conventional seismic resistant structures are based on the design concept of coping with such earthquakes by providing the minimum level of safety required for protecting lives by means of providing the building structural safety through structural strength or ductility. This conventional design concept thus does not sufficiently address the latest demands for the performance of buildings. To address this demand and enhance the structural performance, control systems are incorporated in the structure. Vibration control systems in the form of passive, active, semi-active and Hybrid have been implemented in many structures world wide to address this issue. Tuned Mass Damper (TMD) is a widely accepted and implemented passive vibration damping treatment to suppress vibrations. The effectiveness of Passive TMD depends strongly on the level of tuning and the optimization of various related parameters. The mass ratio ie., mass of structure to mass of TMD and damping in the TMD are important parameters which determine the efficiency of the system. This paper presents analytical investigation carried out to optimize the mass ratio and damping in TMD for structures with different natural period of vibration using four major earthquake data namely, El Centro, Hachinohe, Kobe and Northbridge. Based on the optimized parameters, further studies are carried out to identify various methods to implement the TMD in structures.

## DETERMINING OF DASHPOT OPTIMAL CHARACTERISTICS USING STRUCTURAL CONTROL ALGORITHMS – ID 1329

*A. Soltani, IIEES, Iran (Islamic Republic Of)*
*M. Ziyaeifar, IIEES, Iran (Islamic Republic Of)*

A simple approach in defining optimal characteristics of dashpots and their setting in a high damped passive structural system has been proposed. The efficiency of high damped systems in terms of structural responses is entirely dependent on the arrangement, capacity and nonlinear characteristics of their energy dissipative devices. However, determining optimal configuration and characteristics for dashpots and their setting is a challenge. In this work a methodology is introduced in which the optimality criterion, embedded in the optimal structural control framework, is used to reach to a sub-optimal solution for dashpot nonlinear characteristics. In this approach classical optimal control, in context of semi-active systems, is used to provide the background texture of a prospective passive system with optimal characteristics. Later the provided information can be used in a simple goal seeking algorithm to find the sub-optimal nonlinear characteristics of the dashpots in the specified system. The proposed approach is used to determine the optimal nonlinear characteristics of two structures with different arrangement of viscous dashpots. Later, the process was carried out for different earthquake records. The resultant passive systems with the resolved optimal characteristics have shown a proper margin of adequacy in the context of optimal solution appraisal.

## ACTIVE CONTROL OF NON-SYMMETRIC BUILDING MODELS – ID 1402

*J. C. Jaimes, Instituto de Ingeniería, UNAM, Mexico*

Currently, the seismic design criterion of the several construction codes is based on strength and ductility developed by the structural elements. Nevertheless, it is possible to use mechanical devices in order to control the structural response and to keep the stresses of the structural elements under some limits. In this paper, the response of analytical models of non-symmetric structures controlled by using an idealized active control device is studied. The models are subjected to seismic excitations from different types of soil in Mexico City. The cases in which the controlled response present advantages with respect to the corresponding case of a symmetric model without control designed by using the conventional seismic design are discussed.

## SEISMIC RESPONSE SPECTRA WITH UAFR OF SYSTEMS WITH ENERGY-DISSIPATING DEVICES – ID 1486

*J. L. Rivera, Instituto de ingenieria, Mexico*

An approach is presented for calculating seismic response spectra with uniform annual failure rates (UAFR, F) applicable to structures provided with energy dissipating devices (EDDs). The approach is based on the analysis of single-degree-of-freedom systems with deterministic mechanical properties subjected to simulated ground motions. The approach uses Monte Carlo simulation analysis. The spectra will correspond to systems with different levels of a damage index, associated with several values of VF.

The damage index (ID) used is that proposed by Park and Ang (1983) which contains two terms: the first is the maximum displacement divided by the ultimate displacement, and the second takes into account the normalized hysteretic dissipating energy multiplied by the coefficient "beta". In this study special attention is given to the influence of the parameter "beta". A new definition of this parameter for the EDDs is proposed as a function of the EDDs ductility demand, and its influence on the response spectra with UAFR for systems with EDDs is analyzed.

Values of the expected failure rate VF are calculated for SDOF systems having different vibration period and different values of ID. The formulation takes into account all the possible intensities that can occur at the site of interest. It is done by integrating the absolute value of the derivative of the seismic hazard curve of the site of interest multiplied by the conditional probability of failure of the system, assuming it is subjected to an earthquake with a given intensity.

Failure is defined by the condition that the damage index demand of the systems exceeds the structural capacity (ID$>$1.0).

The simulated ground motions will take into account the evolution in time of both frequency content and intensity. The spectra will correspond to a site in soft soil in Mexico City.

## SEISMIC PERFORMANCE OF A MODULAR TURBO-GENERATORS' BASE ISOLATION SYSTEM – ID 1499

*E. Cruz, U. Catolica, Chile*
*P. Enriquez, PM Ingenieros, Chile*

In projects for the electrical power generation industry in Chile, it has been observed that it is usual that generating plants and also large industrial plants buy second hand turbo-generator equipment, designed (certified) for medium or low seismic demand and end up installing them in areas of high seismic demand. This leaves the equipment outside certification and at risk of being damaged after an earthquake. In this work it is shown that using base isolation as part of the foundation system, the seismic performance of the equipment is greatly improved, and although the site undergoes very strong shaking the equipment is subjected to low intensity earthquake motion. The actual equipment characteristics and the design and operation restrictions are taken from a project recently built in Central Chile. The isolation system is based on low damping rubber bearings, with and without lead core. The Chilean code for base isolated structures is used as the basis for the design of the isolated foundation. Commercial software is used for modeling and analysis. Nonlinear response history analyses are carried out and results for several different earthquake motions are compared for designs with and without base isolation. The earthquake records considered have been obtained in different soil conditions and for earthquakes of different "sizes". The results allow evaluating the effectiveness of the use of base isolation. The most important response parameters (displacement, forces, etc.) are compared for the fixed base and the base isolated designs. It is shown that when base isolation is used the equipment can be operated safely in an area of significantly higher seismicity than the area for which the equipment was originally designed (certified).

### PERFORMANCE OF TUNED MASS DAMPERS FOR RESPONSE REDUCTION OF SEISMICALLY EXCITED NONLINEAR STRUCTURES – ID 1581

*B. Kamrani-Moghaddam, School of Civil Eng. University of Tehran, Iran (Islamic Republic Of)*

The protection of structures is now moving from reliance entirely on the inelastic deformation of the structure to dissipate the energy of severe dynamic loadings, to the application of structural control devices to improve responses to dynamic loads. However, even in controlled structures, it can be expected that large seismic events, will cause structural members to exceed the elastic limit. Since the introduction of tuned mass damper (TMD) by Fahrm in 1909, numerous researches have been studied effectiveness of this device for dynamic loadings. Early applications of TMDs have been directed towards mitigation of wind-induced excitations. Recently, many studies have been carried out to examine the effectiveness of TMDs in reducing seismic response of structures. In this paper, the performance of TMDs in response reduction of nonlinear structures will be addressed. The 3-, 9-, and 20-story structures used for this study were designed by Brandow & Johnston Associates (1996) for the SAC Phase II Steel Project. Time history analysis is performed to calculate the response of each structure subjected to some earthquake records. The same procedure is followed for models with attached TMDs. Comparison of results clarifies TMD's effectiveness on response reduction of structures. A sensitivity analysis will be performed to demonstrate the effects of damper parameters on structural response.

### ACTIVE CONTROL OF IRREGULAR SOIL-BUILDING INTERACTION SYSTEMS – ID 1616

*C. C. Chang, National ChungHsing University, Taiwan*
*C. C. Lin, National ChungHsing University, Taiwan*
*J. F. Wang, National ChungHsing University, Taiwan*

The paper deals with the control performance of active tendon systems for an irregular building, modeled as torsionally-coupled (TC) structure, built on soil site under earthquake excitation. An H-inf direct output feedback control algorithm through minimizing the entropy, a performance index measuring the trade-off between H-inf optimality and H2 optimality, is developed to reduce the TC structural seismic responses. The control forces are calculated directly from the multiplication of output measurements by a pre-calculated time-invariant feedback gain matrix. From parametric studies, it is found that the required number and installation location of sensors and controllers highly depend on the degree of floor eccentricity. In addition, if the soil-structure interaction (SSI) effect governed by the slenderness ratio and the stiffness ratio of soil to superstructure is ignored, the control effectiveness is much less than that of fixed foundation. To obtain the time history responses, a frequency-domain methodology is applied to calculate the frequency response, and then transfer to time domain. It is clearly shown from simulation results that the SSI effect must be considered in the design of the active tendon control device, in particular, for a high-rise building founded on soft site.

### DESIGN AND APPLICATION OF SEISMIC ISOLATION IN CHINA – ID 1632

*F. L. Zhou, Guangzhou University, China*

This paper briefly introduces the recent design, research and application on seismic isolation system for structures (buildings and bridges) in China. Paper introduces some typical testing analysis and researches, including the mechanical tests for isolation bearings, and the shaking table tests for structural models with different location of isolation layers in buildings. Paper also introduces the Chinese design codes for structures with seismic isolation. Paper describes the recent application status and typical examples, especially introduces the largest isolation concrete buildings project in the world now. Also the paper makes discussion for the tendency of future development and some problems existed on seismic isolation technique in China.

### COMPARATIVE STUDY OF DIFFERENT PASSIVE DISSIPATION SYSTEMS: EXAMPLE OF A DESIGN APPLICATION – ID 1636

*P. P. Diotallevi, DISTART - Dept. of Civil Engineering, Italy*
*L. Landi, DISTART - Dept. of Civil Engineering, Italy*
*S. Orlandi, DISTART - Dept. of Civil Engineering, Italy*

This paper focus on the metallic (ADAS), the viscoelastic (VE) and the viscous-fluid (FV) passive dissipative systems, that are among the most efficient innovative system that can be used to improve the seismic response of a building. The first part of this work treats the main specifications and the aim of this devices; also simplified models are presented to easy implement this in the most of the commercial structural programs, like SAP2000. In the second part was applied a simplified procedure to design the three type of devices to obtain a predetermined reduction of one parameter of the response of the structure, for example the displacement of the top storey. This procedure is well know in the technical literature, and it's based on an equivalent linearization of the devices from energetic criterion and on the use of the response spectrum. An extensive campaign of time history analysis was carried out on one and multi degree of freedom shear type r.c. frames for a set of five accelerograms. The result obtained confirm the design methodology, almost for the first mode dominant structures, and give a comparison between the responses of the structure with the various dissipative systems. Finally, in the third part, is presented a study for the application of the viscous-fluid (FV) passive dissipative systems for the seismic retrofitting of an existing italian r.c. building.

### DECENTRALIZED SLIDING MODE CONTROL OF STRUCTURES UNDER EARTHQUAKE LOADINGS – ID 1794

*S. Monajemi-Nejad, Sharif University of Technology, Civil Eng Depart, Iran (Islamic Republic Of)*
*F. Rahimzadeh Rofooei, Sharif University of Technology, Civil Eng Depart, Iran (Islamic Republic Of)*

Active control of building structures using different algorithms and various control mechanisms against earthquake or wind loading has been the center of attention of many researchers.

However, the reliability of these kind of control systems are of main concern. In the present paper, a decentralized control algorithm is considered for actively controlling the response of the tall shear building structures under earthquake excitations. Sliding mode control is used as a base control algorithm and a decentralized scheme of that is presented. In the proposed approach, the building is divided into several substructures and for each subsystem, a separate local control algorithm is designed. The control algorithm consists of the sliding surface and the reaching law equations. A numerical example is used to demonstrate the efficiency of the control algorithm in guaranteeing the system's global stability under the effects of subsystems interconnections and earthquake excitations.

### SEISMIC ISOLATION OF CIVIL BUILDINGS AND NUCLEAR STRUCTURES IN RUSSIA. RESEARCH, DESIGN AND APPLICATIONS – ID 1824

*J. Eisenberg, Central Scientific Research Institute (TsNIISK), Russian Federation*
*V. Belyaev, Center of Capital Construction, Russian Federation*
*V. Smirnov, Central Scientific Research Institute (TsNIISK), Russian Federation*

Three recent research and application Projects are presented. 1. Multistory civil buildings seismoisolation. As seismoisolation in the presented examples rubber bearings are used. A distinctive feature of the solution is non-traditional seismoisolation bearings location. 1) 33-storeyed apartment building in the city of Sochi. The building consists of two equal blocks connected with suspension structures at the level of 16-20 storeys. Rubber bearings are installed in places where the suspended part is supported by the load-bearing structure. 2) 22-storeyed building of administrative-and-trade complex in the city of Sochi. The building consists of 22- storeyed high-rise section of business center and 6-storeyed section of trade center. Bearings are installed at the level of the sixth storey and only provide isolation of high-rise section of the building. 2. Research Project for base isolation with mild steel columns. Experimental studies were provided to investigate the maximum relative horizontal displacements of the tube columns under various axial loads from 0 to maximum stability critical values. The 1/5 to1/7 models were tested. RC columns in ground stories collapse during relatively low horizontal displacements. In the contrast mild steel columns preserve bearing capacity until relatively large horizontal displacements corresponding to 8-9 MSK intensity degree earthquakes. 3. A new solution of multicomponent low-frequency-damped seismic isolation system for VVER-640 NPP reactor building protection against very strong earthquakes. A new engineering solution of multicomponent low-frequency damped seismic isolation system. VVER-640 NPP reactor building is presented. The mass of the object to be protected may be 75000 tons and higher, the height may exceed 75 meters. Problems of choosing the optimal layout for seismic isolation devices in a 3D low-frequency seismic isolation system of a high risk reactor building are considered.

## ES 3e: Structural Engineering - Experimental

Level-1

### SEISMIC DESIGN OF COMPOSITE STEEL AND CONCRETE BASE COLUMN CONNECTIONS – ID 47

*L. Di Sarno, University of Sannio, Italy*

The present study provides an insight in the inelastic response of steel and concrete composite columns. Effects of connection details on the member response are investigated both experimentally and analytically. Several column specimens with different base connections have been designed according to the guidelines of European Standards and tested in the University of Naples, Italy. Two types of column connections, named 'traditional' and 'innovative' have been considered. The former consists of tapered steel plates welded onto the base plate and anchored to the foundation block through steel bolted bars. The latter is a socket type connection in which the column is fixed to the foundation block through special concrete filler. Monotonic tests with increasing lateral loads and different levels of axial loads have been carried. Numerical models have been calibrated and used to predict the inelastic response of the tested specimen. In so doing, pull-out tests have been used to define the relationships at the interface between the anchorage bolts and concrete block. Simplified mechanical models and design rules are provided for the innovative socket-type connections. The results of the experimental and numerical analyses carried out demonstrate that traditional base plate connections give rise to large concentrations of damage in the anchorage bolts. The energy dissipation is primarily caused by friction; this mechanism is not reliable and should be avoided particularly in earthquake resistant structures, where large alternate seismic actions may take place (moderate-to-high magnitude earthquakes). Conversely, socket type connections are more dissipative and stable and hence can be reliably used for the capacity design of structures. Numerical analyses show that the contribution of the column base connection to the total lateral drift depends significantly on the connection details. Additionally, design rules based on simplified mechanical models are provided; such rules can be implemented in seismic design codes of practice.

### EUROSEISTEST: A EUROPEAN LARGE SCALE TEST SITE FACILITY AT VOLVI-GREECE – ID 95

*K. Pitilakis, Aristotle University Thessaloniki, Greece*
*G. Manos, Aristotle University Thessaloniki, Greece*

This paper includes an overview of the activities and capabilities of the EuroseisTest- Aristotle University Thessaloniki. This is a unique European research infrastructure established through EU funding in 1994 and operating continuously since then, generating numerous high quality data and scientific outcome published in more than 150 papers. It consists of laboratory and in-situ facilities, the later being the core of the infrastructure. The experimental facilities of EUROSEITEST are composed, of two specific facilities (only from inter-University administration point of view): a) The geotechnical facilities (free field 3D permanent strong ground motion network and laboratory of soil dynamics) (AUTH-LGEE, Director: Professor Kyriazis Pitilakis) and b) The structural facilities AUTH-LSMS operating the free field and laboratory structural parts of the infrastructure, including a shaking table and a strong reaction frame. Director: Professor George Manos). More specifically, a whole valley in the epicentral area of the strong Thessaloniki earthquake (June 1978, Ms=6.5), 25km NE from Thessaloniki, is instrumented with a dense 3D accelerometric array. Model structures were erected and instrumented in the centre of this valley and have been extensively tested. The high seismicity of the region, the close distance from Aristotle University, the already existing network (surface and down-hole) both in the instrumented valley and in the city of Thessaloniki, the auxiliary laboratory facilities (soil dynamics etc), the very good knowledge of the geometry of the valley and the soil conditions, (through numerous previous experiments and tests), the important database of seismic recordings and the combined studies already existing, and above all, the long experience earned the past ten years from this experimental test site, all these make this infrastructure an ideal test site to support integrated research activity in engineering seismology and soil dynamics (site effects) as well as in earthquake engineering (soil-structure interaction and seismic behaviour of structures).

### HEALTH MONITORING OF PARTIALLY INSTRUMENTED STRUCTURES – ID 124

*M. P. Limongelli, Politecnico di Milano, Italy*

Monitoring technique based on the analysis of responses recorded on the structure are becoming a widespread method to monitor structural health conditions. The conventional visual

inspection is not always able to timely detect deterioration allowing a prompt intervention. Moreover visual inspection requires a large amount of time and is prone to human errors. For these reasons and thank to the advance in sensor technology, data acquisition systems and data interpretation algorithms, monitoring technique based on the analysis of responses recorded on the structure are becoming a widespread method to monitor structural health conditions. Acceleration responses are used to analyze structural behavior during both strong seismic events and the everyday life of the structure. An effective monitoring system should be characterized by three main requirements: accuracy of the recorded data, cost-effectiveness of the sensors systems, availability of procedures to interpret the recorded data. Due to economic reasons structures are usually instrumented with a limited number of sensors. The economic advantage associated to the lower cost of the sensors system is counterbalanced by the lack of data in location where recording sensors are not available. In this paper a tentative solution to this problem is proposed through a method to reconstruct unknown responses from the ones recorded by a limited number of sensors. Comparison between reconstructed responses can be used as a guide in the process of damage detection. The economic advantage associated to the lower cost of the sensors system is counterbalanced by the lack of data in location where recording sensors are not available. All these problems are addressed in the paper and an effectiveness function is proposed to quantify the cost effectiveness of the employed set of sensors.

## COMPUTATIONAL SYSTEM FOR IDENTIFICATION IN EXPERIMENTAL DYNAMICS – ID 129

*P. García Valery, Instituto de Materiales y Modelos Estructurales, Venezuela*
*C. Genatios, Instituto de Materiales y Modelos Estructurales, Venezuela*
*F. Garcés, Instituto de Materiales y Modelos Estructurales, Venezuela*
*M. Lafuente, instituto de Materiales y Modelos Estructurales, Venezuela*

This article resumes the main features of a computational system for structural dynamics simulation, experimental identification and model correction. The first part includes modelling of conventional shear walled or framed buildings and response evaluation following conventional dynamic analysis procedures. The second part executes identification procedures for the evaluation of the dynamic properties of buildings subjected to dynamic essais. The third part performs the correction of analytical models following two identification procedures that include non parametric ortogonalization of the mass matrix. A complete example is developed in order to show the system's performance.

## EXPERIMENTAL EVALUATION OF LATERAL STIFFNESS OF CONFINED MASONRY STRUCTURES – ID 130

*F. Garcés, Instituto de Meteriales y Modelos Estructurales, Venezuela*
*C. Genatios, Instituto de Materiales y Modelos Estructurales, Venezuela*
*M. Lafuente, Instituto de Materiales y Modelos Estructurales, Venezuela*

This article presents an identification method for the assessment of stiffness coefficients due to shear (GA) and flexural (EI) behavior, of confined masonry structures. The numerical evaluation is based on experimental data and considers the influence of various mass models. A non parametric method is employed for mass model identification, and an identification method is presented for the evaluation of the stiffness of shear wall structures, both requiring experimental data. The influence of various mass models is evaluated. A procedure employed in the evaluation of the stiffness variation of shear wall buildings is proposed, and a numerical example is evaluated, leading to satisfactory results.

## SEISMIC PERFORMANCE OF RC BEAM-COLUMNS JOINTS RETROFITTED USING LIGHT RC JACKET : EXPERIMENTAL STUDY – ID 136

*C. Karayannis, Democritus University of Thrace - Civil Eng. Dept., Greece*
*G. Sirkelis, Democritus University of Thrace - Civil Eng. Dept., Greece*
*C. Chalioris, Democritus University of Thrace - Civil Eng. Dept., Greece*

One of the most common techniques for the retrofit of Reinforced Concrete (RC) frames is the use of concrete jackets that encase the existing column along with the joint region. It is proved that jacketing techniques provide increased joint strength, shift the failure to the beam, and increase overall lateral strength and energy dissipation. However, jacketing increases the member sizes, reduces the available floor space, increases mass and thus alters the dynamic characteristics of the structure that may cause increased demands at unintended locations.

In this study, the use of a light type of RC jacket for damaged RC beam-columns subassemblages is proposed and experimentally investigated. The examined jacket has very slight thickness (20mm) and dense reinforcement that consists of small diameter (5.5mm) horizontal and vertical steel reinforcement. This jacketing applies only at the joint region and a narrow part of the conjunct columns and beam, close to the joint body.

The main advantage of the proposed light jacketing comparing to the commonly used jacketing is the fact that it slightly changes the initial size. Thus, the available floor space and the mass practically are not modified and the distribution of shears among the columns remains practically the same.

Two specimens were constructed and subjected to constantly increased cyclic loading. Columns length and cross-section dimensions were 1800mm and 200/300mm, respectively, and beam length and cross-section dimensions were 1100mm and 200/300mm, respectively. After the initial loading, damaged specimens were retrofitted using the proposed light RC jackets. Retrofitted specimens were retested with the same cyclic loading sequence. To assess the effectiveness of the applied jacketing technique the hysteretic responses of the repaired specimens are examined and compared to the initial ones in terms of maximum loading, stiffness and absorbed energy per cycle.

## PSEUDO-FORCE CONTROL METHOD FOR REAL-TIME SUBSTRUCTURE TESTING WITH IMPLICIT INTEGRATION ALGORITHMS – ID 161

*B. Wu, Harbin Institute of Technology, China*

The real-time substructure testing (RST) is a seismic experimental method, in which a real-time test is performed on a structure split into a physical test specimen of a key part and a numerical model of the remainder, with data passed between them at each timestep. For RST of systems with many degrees of freedom, an integration method with unconditional stability is highly desirable. The author of this paper and his co-workers investigated the numerical behavior of the operator-splitting method in RST (OSM-RST) and found that the OSM-RST is unconditionally stable so long as the non-linear stiffness and damping are of the softening type (i.e. the tangent stiffness and damping never exceed the initial values). The particular advantage of the OSM-RST over other unconditionally stable methods is its explicit formulation. However, the dissipation property of the OSM-RST is poor: it produces negative numerical damping if the experimental substructure is with damping. On the other hand, the actual performance of RST depends on the actuator time delay which has an effect equivalent to negative damping. This will render the OSM-RST conditionally stable.

The unsatisfactory numerical behavior of the OSM-RST and its failure as an unconditionally stable algorithm due to the actuator delay drive one to seek other integration methods with good dissipation property. These include the Newmark method with gama-damping, alpha-method, Houbolt method and Wilson method. But all of them are implicit methods. One of such methods, alpha-method, has been implemented in RST by Shing

et al., despite the extra difficulties of iteration in the high speed of testing execution. This paper proposes a new method, namely pseudo-force control method, aiming to cancel the mathematical iteration by the use of feedback control. The alpha-method will be used as an example of implicit integration methods.

### EVALUATION OF THE ENERGY DISSIPATED BY HYSTERESIS IN R/C SHEAR WALLS USING PARAMETERS OF DISPLACEMENT – ID 166

*C. Oyarzo Vera, Universidad Catolica de la Santisima Concepcion, Chile*

The energy dissipated by hysteresis in structures under reversible load patterns is one of the most widely used parameters to evaluate the cumulative effect of the load history (cumulative damage), to identify the different behavior between elements whose failure is dominated by the flexion or shear and many others phenomena.

However, to evaluate this parameter it is necessary to have a full load-displacement history record of each one of the members of the structure under study.

This paper present the results of the tests made over reinforced concrete walls designed with the same quantity of longitudinal reinforcement and different quantities of transversal steel. The objective of the differences in reinforcement are to have an equal resistance to flexion, but different resistance to shear. These walls were tested under reversible loads until the failure.

From the analysis of the loads-displacement records, it was possible to define a mathematical model which represents the behavior of the energy dissipated by hysteresis using the cumulate ductility of displacements measured during the test.

There are two stages defined in this model. The first one represents -by a linear equation- the dissipation of energy by hysteresis when the behavior of the wall is dominated by flexion.

The second stage -also linear- represents the dissipation of energy by hysteresis when the behavior of wall is dominated by shear. For this model it uses a parameter named gamma, which corresponds to the slope of the second stage of the model, lower than the first stage. Gamma depends on the ratio ultimate shear v/s nominal shear, the quantity of transversal steel, the load history and others.

With this work, it is possible to make a mathematical model which defines a relationship between the energy dissipated by hysteresis and the cumulate ductility of displacement, which is easier to measure.

### DYNAMIC RESPONSE ASSESSMENT OF BUILDING FROM MICROTREMOR MEASUREMENTS IN GUADELOUPE, FRANCE. – ID 177

*E. Bertrand, LRPC - CETE Méditerranée, France*
*A. M. Duval, Méditerranée, France*
*S. Vidal, Méditerranée, France*

Microtremor measurements can be used to estimate the structural dynamic characteristics of building. Some previous studies have already shown that the results obtained with these methods can be extrapolated to the building behaviour under seismic action. These kinds of analysis have a real financial advantage compared to the more traditional ones. In addition, because of the weak motions, the building is not damaged by the field survey.

The measurements that we propose can be in particular useful to fix numerical modelling of the building but also it can help for the damage detection after an earthquake by comparison of the recordings before and after the event. It allows estimating not only the natural frequencies of the building but also mode shapes and damping ratios. Furthermore, by looking to the phase of the recordings we are able to separate the torsional modes from the translational ones.

In November 2004 a magnitude 6.3 earthquake stroke Guadeloupe Island in the French West Indies. During the following months, several aftershocks occurred close to the Island "Les Saintes". The biggest one reached a magnitude of 5.7 the 14th of February 2005. We present in this paper an application of the methodology on two different buildings affected by this seismic crisis. The first one, a 6 storey RC building has been lightly damage by both the main shock and the February one. We conducted two surveys on this building, one several days before the aftershock and the second one 10 months later. Comparison in the vibration frequencies resulting from our measurements shows that structural damages were not worsen by the second earthquake. The second experiment concern a traditional housing characterized by a large asymmetrical transparency at the ground floor. The computation of a torsional spectrum (Dunand, 2005) illustrates clearly this asymmetrical comportment under seismic loading.

### RETROFITTING R/C BRIDGE PIER TYPE CROSS-SECTIONS WITH PARTIAL CONFINEMENT EMPLOYING CFRPS – ID 198

*G. Manos, Aristotle University Thessaloniki, Greece*
*V. Kourtidis, Aristotle University Thessaloniki, Greece*

The upgrading of reinforced concrete (R/C) cross-sections, with one side rather longer than the other ($h/b > 1.5$), by partial application of CFRP (Carbon Fibre Reinforcing Plastic) confinement is investigated here. This partial application of CFRP confinement is aimed at the retrofitting of bridge-pier type R/C cross-sections in order to prohibit, up to a point, the development of premature compressive failure at the base of the pier due to combined compression and flexure from seismic loads. It may also be applied to retrofitting similar vertical structural members with non-accessible sides. Such a scheme is studied here using CFRP layers that do not extend all around the cross-section ("partial confinement"). To compensate for the fact that the CFRP layers do not enclose the cross-section entirely, anchorage of these layers must be provided. To this end, a laboratory investigation was carried out to study the effectiveness of such partial confinement together with alternative anchorage schemes. Identical column-specimens, constructed with prototype materials having a height of 1600mm and a cross section 300mm by 200mm, were tested. They were subjected to compressive loads as this type of stress field is expected to develop at the base of such vertical members under combined vertical loads and seismic actions, where undesired compression failure may develop. With the successful application of this partial confinement, an increase of almost 50% was observed in this compression capacity of the test specimens. Moreover, the deformability of these specimens was substantially increased, demonstrating the effectiveness of this type of partial confinement. It was also demonstrated from the experimental sequence that critical factors for this effectiveness were the type of anchorage of the CFRP partial confinement and the number of CFRP layers.

### LARGE SCALE EARTHQUAKE TESTING FACILITY FOR VULNERABILITY ASSESSMENT – ID 212

*T. Payen, CEA-Saclay, France*
*J. C. Queval, CEA-Saclay, France*
*P. Sollogoub, CEA-Saclay, France*

EMSI Laboratory of CEA Saclay is involved in seismic testing of civil engineering structures and mechanical equipment, with a unique testing facility, TAMARIS, with AZALEE, the largest table in Europe (6 m X 6 m with 100 tons payload). In parallel, EMSI Laboratory has a large experience in numerical approaches for simulation (CAST3M code). Many national and international research programs have been performed successfully but testing needs are evolving.

The earthquakes that occurred worldwide in the last decade, have shown significant progress in earthquake engineering. Nevertheless, these events have all indicated important deficiencies in our understanding of induced phenomena during earthquakes. As a consequence, intensive seismic research is necessary, which must be based on sound experimental results, simulating the conditions actually occurring in a real earthquake.

The need for experimental studies is pushed by the increasing of the global vulnerability of our societies and the evolution of design approaches asking to performance evaluation of structures. This is

applicable to existing and new constructions.

CEA have launched an extension project of his facility in order to fulfil these new requirements. The following characteristics are considered: Large scale, three dimensional excitations, two coupled shake tables, high performance actuators... This facility is expected to become a powerful tool for European or international collaboration in seismic engineering research.

The objective of this paper is to describe the outline of research topics in seismic domain for the next decades in relation to the new project of large scale earthquake testing facility. A description of the outline of the new testing facility is given.

## SEISMIC BEHAVIOR OF PRECAST/POST-TENSIONED REINFORCED CONCRETE BEAM TO COLUMN CONNECTIONS – ID 218

*C. Chin-Tung, NKFUST, Taiwan*
*C. T. Liu, NKFUST, Taiwan*

The precast and post-tensioned structures have the advantage of self-centering and thereby eliminate permanent drift and reduce the possibility of being demolished after an earthquake. Literatures proved that the precast/post-tensioned building systems have steady responses under cyclic loading. In this research, four precast/post-tensioned RC beam-column connections have been constructed and tested. Steel or plastic plates were cast on the beam-ends and column faces before the pour of concrete. RC beams and columns were precast and then connected by unbonded post-tensioned strands. Finally, energy dissipating devices either buckling restrained steel bars in the precast slots of beam-ends to connect the column by threads, or steel angles anchored by bolts in the precast holes of beam-ends and column were installed. The investigated parameters include beam to column interfaces (steel on steel or plastic on plastic), energy dissipating devices (steel bars or angles) as well as the spacing of hoops in the panel zone. With larger spacing in the panel zone and steel interface, two specimens failed due to panel shear with diagonal cracks from corner to corner of the panel zone. With less spacing in the panel zone and plastic interface, the specimen performed in a way of self–centering, however, strength deteriorated after the loading cycle of 3% drift due to concrete crushing in the corner of beam-ends. Hysteretic loops showed that the energy-dissipating capacity of specimens with steel angles or bucking restrained steel bars are satisfactory. However, the force transmitted by bucking restrained steel bars resulted in larger panel shear for the specimen.

## ASSESSMENT OF NON-LINEAR SHAKING TABLE SPECIMEN INTERACTION – ID 223

*A. Crewe, University of Bristol, UK*

An earthquake shaking table is a device for shaking large structural models and components with a wide range of simulated ground motions, including reproductions of recorded earthquakes. It typically consists of a large, rectangular platform (or table) that is driven in up to six degrees of freedom by servo-hydraulic actuators. Shaking tables are essential tools in earthquake engineering research since they allow study of the effects of true inertia forces on the test specimens and they are used throughout the world for research into the dynamic effects of earthquakes on structures.

However, shaking tables are complex electro-mechanical systems and in many cases the specimen being tested on the table interacts significantly with the dynamic characteristics and performance of the table itself. This paper describes a series of tests of a non-linear specimen that were used to investigate the interaction between the specimen dynamics and the dynamics of the shaking table at Bristol University.

In order to perform repeatable tests of a highly non-linear specimen, a 14,000kg specimen with controllable nonlinearity was developed as part of an EU funded project. The specimen comprises a mass of up to 7000kg hanging in a support frame. In the axis of motion of the mass there are air springs that provide a variable stiffness to the movement of the mass. The air pressure in the air springs can be released through adjustable pneumatic values to reduce the natural frequency of the specimen over a period of between 0.5 and 5 seconds at any point during the testing.

Control of the shaking table while carrying this non-linear specimen was very difficult and this paper describes and compares various strategies that can adopted if a non-linear specimen is to be tested effectively on a shaking table.

## LNEC-SPA, A COMPLETE SHAKING TABLE TEST ANALYSIS TOOL – ID 244

*L. A. M. Mendes, National Laboratory of Civil Engineering, Portugal*
*A. Campos Costa, National Laboratory of Civil Engineering, Portugal*
*E. Coelho, National Laboratory of Civil Engineering, Portugal*

This paper describes a windows based interactive computer tool developed in LNEC, to analyze the results of shaking table tests and other dynamic experiments. The program is implemented in LabView*, using the native signal analysis toolkits and external routines to compute the more intensive calculations, which were developed mainly in Fortran. The code is divided in separate modules all using an efficient data storing scheme. The main modules are: signal generation, used to define the earthquake scenarios that are injected to the shaking table; data acquisition to format and acquire signals from DAQ boards; signal analysis, used to edit, filter, apply windows and frequency domain tools (e.g. FFT, PSD, Elastic Response Spectra, etc.) and to assess ground motion parameters (e.g. Arias intensity, A95 Parameter, Housner Spectrum Intensity, etc.); math channels, used to calculate runtime defined mathematical channels using the data collected during the tests; system identification, to determinate the experimental modal frequencies and damping; simplified multi-degree-of-freedom model, to assess the global behaviour of lumped mass systems using only cinematic quantities allowing the evaluation of inertia forces, dissipated energy and force-displacements relations; and, finally, a real-time dynamic visualization module which is an important tool for data interpretation of shaking table test results. In parallel with the presentation of the computer program is also discussed some theoretical fundaments and practical issues of the techniques used in LNEC to analyze the huge amount of data that experimental shaking table testing programmes provide. It is also briefly presented the application to a two storey, 1:3 scaled, RC precast structure tested in LNEC's triaxial shaking table.

*Labview is patent software of the National Instruments Company.

## SHAKING TABLE TEST OF 1/3 SCALE MODEL OF PIPELINE SYSTEM PART 2: ANALYTICAL RESULTS – ID 264

*V. Hristovski, IZIIS, Macedonia*
*L. Tashkov, IZIIS, Macedonia*
*L. Krstevska, IZIIS, Macedonia*
*B. Temelkovska, Thermal Power Plant, Macedonia*
*M. Jovanovic, IZIIS, Macedonia*

In the companion paper with the same main title, Part 1: Experimental results, the important role of the pipeline systems in proper functioning of the integral system for production of electricity at thermal power plant (TPP) has been emphasized. In order to increase the exploration period of the pipeline systems, it is necessary to investigate the restraining conditions (spring hanging and supports) under dynamic and seismic loading. The subject of this paper is numerical simulation and verification of the performed experimental tests in IZIIS-Skopje on a 1/3 scale model of a segment of a pipeline system for evaluation of its dynamic characteristics by means of ambient and forced vibration method, as well as dynamic shaking table tests using input records in terms of acceleration time histories. The analytical models are based on the finite element method, using the SAP2000 computer program. The special attention has been paid on the modeling of the boundary conditions, as well as of the spring stiffness properties. The parametric analyses have showed the

sensitivities of the results using models with different properties of link elements and different boundary conditions. The general impression is that both approaches – experimental and analytical, as complementary phases, are needed for investigation of this kind of problems. The experiments give us information about the stiffness properties in details (especially for springs, and for estimation of the boundary conditions, as well), or they verify some previous quasi-static basic tests on this springs, and in turn, the analyses, using this information as input, give us complete image of the stress-strain distribution in all elements, which is not always possible during the experimental tests. Using this complementary experimental-analytical approach, very reasonable and comparable agreement of the experimental and numerical results, as well as useful practical analytical tool have been obtained.

### HYSTERETIC ENERGY DISSIPATION IN LATERALLY RESTRAINED STEEL TUBE AND SOLID BAR BRACES – ID 274

*O. C. Celik, Istanbul Technical University, Turkey*
*J. W. Berman, University at Buffalo, United States*
*M. Bruneau, University at Buffalo, United States*

This paper describes an experimental investigation into the seismic behavior and efficiency of steel frames with special bracing infills. Cold formed steel studs (CFSS), typically used in nonstructural partition walls, were studied to determine if they could be used to laterally restrain braces against buckling and thus enhance their seismic performance, since compression buckling can cause rapid strength degradation and loss of ductility in braces. Four specimens were designed using ductile seismic design principles and then tested under cyclic loading. Specimens have either single diagonal tube or solid bar X braces with and without CFSS and U brackets providing out-of-plane and in-plane buckling restraint respectively.

Behavioral characteristics of the specimens are quantified with an emphasis on hysteretic energy dissipation. The effects of KL/r ratio, bracing configuration, and cross-section type are also discussed. Experimental results show that, at the same ductility levels, the cumulative energy dissipation of braces can be significantly increased when CFSS members are used. However, when tubular cross sections are used for braces, local buckling led to a reduced fracture life compared to the case without CFSS members. CFSS members appear to be relatively more effective when solid bar braces having large slenderness (tension-only braces) are used, since the difference between dissipated energies obtained with and without studs is substantial. As a result, the CFSS members showed promise for use in new buildings or as an efficient retrofitting technique in existing buildings that lack strength, stiffness, and ductility.

### EXPERIMENTAL STUDY OF THE BAMBOO-MUD-WALL USED IN TAIWANESE HISTORIC BUILDING – ID 302

*C. Chia-Chi, National Cheng-Kung University, Taiwan*
*T. Meng-Ting, National Cheng-Kung University, Taiwan*
*C. Ja-Shian, National Cheng-Kung University, Taiwan*
*S. Chung-Hsien, National Cheng-Kung University, Taiwan*

In Taiwan , the bamboo-mud-wall is the main structural element of most of the existing wooden historic buildings . For investigating the structural behavior of the bamboo-mud-wall , in this study , totally 13 specimens including different construction , different material , and different height-to-width ratio are tested under horizontally cyclic loading .

From the test , followings are observed :

1. Under the cyclic loading , the specimen gets compression failure at the corner first , then suffers shear failure of the wall panel . 2. The ultimate load of the wall specimen is influenced by the arrangement of horizontal and vertical Nuki (complemenyary member) . 3. In the wall specimens , in general , the wooden frame provides 1/3 strength , and mud provides 2/3 strength . 4. The recorded hysteresis loop of the wall specimens can be simplyfied as several rules. Following these rules, the load-displacement relationship of the bamboo-mud-wall under cyclic loading or time history loading can be generated .

In addition , for assessment application , an eguivalent bracing model of the bamboo-mud-wall is established based upon the test results . This study provides the conservation designer or architect the fundamental informations for seismic evaluation and retrofit design of wooden historic building.

### NON-DESTRUCTIVE GEOPHYSICAL SURVEYS FOR DYNAMIC CHARACTERIZATION OF MALLORCA CATHEDRAL – ID 304

*J. O. Caselles, UPC, Spain*
*G. Martinez, UMSNH, Mexico*
*J. Clapes, UPC, Spain*
*P. Roca, UPC, Spain*
*J. A. Canas, UPC, Spain*

For the dynamic characterization of Santa Maria Cathedral in Palma de Mallorca, some non-destructive geophysical surveys were applied. Seismic tomographies and GPR surveys were performed to characterize the properties and inner structure of walls, buttresses and columns and identify zones of cracks and fractures. Natural vibration and low motion seismograms were also recorded on different location of the Cathedral to adjust lineal and a non-lineal modelling. Finally, H/V spectral ratios with noise signals were computed in and around it to characterize soil resonance frequencies and possible interaction between the soil and the structure. One GPR profile with a 900 MHz antenna was made in each column, two profiles in six walls, two profiles in three buttresses and one profile in the extern wall crossing perpendicular buttresses. Also 40 GPR profiles with the 1.5 GHz antenna were made in each of three columns for 3-D reconstruction. For seismic tomography, 120 ray traces in each of the three columns were performed to assure high coverage. A high frequency waves were generated by an instrumented hammer, and waves were recorded by a piezoelectric accelerometer at more than 65000 counts per second to assure high quality arrival times. To estimate possible soil-structure interaction and define the soil filling area more than 15 triaxial noise signals were measured around the Cathedral and more than 10 inside it, computing in each one the H/V spectral ratio. Finally, for dynamic characterization, we recorded noise acceleration spectra in more than 20 important locations and a great amount of low magnitude local and high magnitude teleseismic earthquakes in the upper part. All of these surveys carried out serve to characterize the entire Cathedral in order of evaluate its structural state.

### DYNAMIC INVESTIGATIONS AND LINEAR ANALYSIS OF THE MALLORCA CATHEDRAL – ID 305

*G. Martinez, UMSNH, Mexico*
*P. Roca, UPC, Spain*
*J. O. Caselles, UPC, Spain*
*J. Clapes, UPC, Spain*
*J. A. Canas, UPC, Spain*

The Mallorca Cathedral is located in the main of the Balearic Islands in Spain. It is one of the largest Gothic cathedrals in Europe and it was built during the second half of the13th century, and continued through 14th and 15th century. This paper describes the analysis performed for the dynamic structural behavior characterization of the main structure of the building using ambient vibration measurements in different points on the chapels, main nave and lateral naves, this investigation was carried out to obtain an experimental estimation of the vibration modal frequencies of the building. On the other hand, with the goal of analyze the possible amplification effects between soil-structure system, the foundation soil dynamic response characterization was calculated using the H/V relationship applied to several points in and out the cathedral perimeter. As a complement, in the present work a linear 3D finite element model was built and updated using the site measured dynamic parameters. This model was subject to a 475 and 975 years return period earthquake in order to establish future behavior estimation for this building before a certain seismic scenario.

### SEISMIC DAMAGE DETECTION USING SMART PIEZO-TRANSDUCERS AND ELECTRO-MECHANICAL IMPEDANCE SIGNATURES – ID 307

*C. Providakis, Technical University of Crete, Greece*
*M. Voutetaki, Technical University of Crete, Greece*

Civil infrastructures deteriorate during design life due to various factors such as overloading, natural disasters and deficient maintenance. The prompt condition assessment of critical civil facilities after a severe earthquake is an important procedure to prevent and mitigate secondary disaster. Most of the conventional nondestructive evaluation (NDE) methods require accessibility to the inspected structural components that is not always possible for real-time civil infrastructure assessment following an earthquake. On the other hand, typical low-frequency vibration based damage detection techniques demand intensive computations to process measured data. The electromechanical impedance (EMI) health monitoring technique was initially proposed and tested on mechanical and aerospace structural components and a number of experimental investigations have been successfully performed on civil engineering structures and proved to be a very promising technique for in situ health monitoring of civil infrastructures. In particular, the electro-mechanical impedance technique uses smart piezoelectric ceramic (PZT) materials as sensors/actuators and in order to ensure high sensitivity to incipient damage, a high frequency electromechanical admittance (admittance is the inverse of impedance) signature of the PZT material serves as a diagnostic signature of the structural component. This paper describes the performance of the electromechanical impedance technique for damage detection in concrete structural components. For this purpose, a high-frequency numerical modeling is performed by using the finite element method. The electric admittance spectrum is obtained and evaluated at the terminals of the PZT sensor/actuator. Several conditions were imposed to simulate real-time damage, and the efficiency of the EMI method in tracking and monitoring the integrity of civil structural facilities.

### REPAIR OF LARGE SCALE REINFORCED CONCRETE FRAMED SHEAR WALLS BY STEEL PLATES – ID 354

*Y. W. Liou, Chia Nan University of Pharmacy & Science, Taiwan*
*Y. J. Chiou, National Cheng-Kung University, Taiwan*
*C. C. Huang, National Cheng-Kung University, Taiwan*
*M. S. Sheu, National Cheng-Kung University, Taiwan*

The quantitative evaluation of earthquake resistance capacity for the repair of damaged structure is investigated in this study. Ten large-scale framed wall specimens repaired by steel plates were test, and a simple formula is proposed to predict the behavior of these structures. The experimental results showed that the ultimate strength of framed shear walls only rapidly repaired columns by steel plates can possess almost the same strength of the prototype specimen. However, the ultimate strengths of the specimens repaired by injection of epoxy first, and then repaired columns by steel plates are fifty percent higher than those of the prototype specimens.

### MODAL IDENTIFICATION OF A STONE MASONRY CHURCH , IN LAGOS PORTUGAL, DURING REHABILITATION PROCESS – ID 371

*M. A. Viana Baptista, ISEL/CGUL/IDL, Portugal*
*J. P. Costa, STAP OZ, Portugal*
*P. Silva, ISEL, Portugal*
*P. Mendes, ISEL, Portugal*
*R. Brincker, U Aalborg, Denmark*

The Nun's church, in Lagos – Algarve, it is part of its cultural heritage. The church was built in the 16th century, prior to the great Lisbon earthquake of the 1st November 1755. The church was destroyed by this earthquake and was partially rebuilt after it. The church remained open to the public until the occurrence of a 7.9 magnitude event on February 1969, since then no significant retrofit was performed. The church is a stone masonry structure with a unique central nave covered by a barrel vault. A spherical dome is located over the High Chapel. The external walls discharge directly onto the soil. The main structural concern is a large longitudinal crack along the main barrel vault. Due to a critical vertical deformation. Ambient Vibration tests were performed during different phases of retrofit and these were used for Finite Element Model Updating. In this work we present: the major results of the pathology survey (by STAP-OZ); the Finite Element Model and the results of the Ambient Vibrations Results, obtained until now: before start of the rehabilitation process; after the propping of its vaults.

### AMBIENT VIBRATION MEASUREMENTS ON A CABLE STAYED BRIDGE – ID 414

*A. Kibboua, National Earthquake Engineering Centre (CGS), Algeria*
*M. N. Farsi, National Earthquake Engineering Centre (CGS), Algeria*
*J. L. Chatelain, Institut pour la Recherche en Développement (IRD), France*
*B. Guillier, Institut pour la Recherche en Développement (IRD), France*

The last earthquakes of Loma Prieta (USA, 1989), Kobe (Japan, 1995), Izmit (Turkey, 1999), Chi-chi (Taiwan, 1999) confirmed that the bridges could be very vulnerable structures under dynamic loading. The seismic response analysis of an existing bridge needs a mathematical model that can be calibrated with measured dynamic characteristics. These characteristics are the periods and the associated mode shapes of vibration and the modal damping coefficient. The proposed work concerns the execution and interpretation of the results of ambient vibration tests done on a cable stayed bridge across the Oued Dib River (Mila / Algeria). The signal analysis of ambient vibration records will permit to determine the dynamic characteristics of the bridge. On the other hand, we develop a 3-D model of the bridge in order to assess the frequencies and the associated modes of vibration. This information will be necessary in the planning of the test on the site (locations of the sensors, frequencies to be measured and the associated mode shapes of vibration.

Keywords: ambient vibration, cable stayed bridge, dynamic characteristics, numerical model

### SEISMIC RETROFITTING OF SUBSTANDARD REINFORCED CONCRETE PRISMATIC MEMBERS USING COMPOSITE JACKETS – ID 451

*G. Thermou, Demokritus University of Thrace, Greece*
*D. Syntzirma, Demokritus University of Thrace, Greece*
*S. Pantazopoulou, Demokritus University of Thrace, Greece*

An experimental study has been conducted in order to investigate the efficiency of composite jackets in upgrading the seismic behavior of substandard reinforced concrete prismatic members. The experimental program comprised sixteen (16) square cross section cantilever specimens representative of a typical building column from column mid–height between floors to the beam-column connection at a scale of 1:2. Due to lack of adequate seismic detailing the specimens were susceptible to various modes of failure such as shear failure, buckling or failure in the lap splice region. The as-built specimens were first damaged up to failure after being subjecting to simulated seismic loading. In the next phase, the specimens were retrofitted with composite jackets and then loaded again under cyclic lateral displacement reversals simulating earthquake effects under constant axial load. The efficiency of the composite jackets as an intervention method for the seismic upgrading of substandard reinforced concrete members was investigated taking into consideration parameters related to the type of composite fabric chosen for the intervention (glass, carbon or metallic), the type of the load history applied (near fault

ground motion characteristics) and the level of damage to which the as-built specimens were subjected prior to repair. The results of the experimental research provide valuable information relative to the degree of participation of the composite jackets to the various resistance mechanisms, their ability to reverse the effect of the pre-damage and increase the deformation capacity of the structural member so as to behave in a ductile manner.

### SEISMIC BEHAVIOUR OF REINFORCED CONCRETE COLUMN WITH WINGS – ID 499

*L. Kuo-Chiang, Yung Ta Instutute of Technology and Commerce, Taiwan*
*L. Yuh-Wehn, Chia-Nan University, Taiwan*
*H. Wen-Chun, Cheng-Kung University, Taiwan*

It is an important topic to promote the building resistance under earthquake. From the inspection of hazard of buildings in earthquake the failure performance of columns caused the building inclined even collapsed. Reinforced concrete column with wings is a good way to retrofit and strengthen aboriginal column to promote its bearing capacity under earthquake. The purpose of this paper was to carry out both experimental and theoretical investigations of reinforced concrete column with wings subjected to horizontal forces under constant compression load. Ten specimens each with column section 20cm * 20cm and 135cm in height, 10cm to 40cm width of wings with 10cm and 15cm thick, were used to detect the seismic behavior of reinforced concrete with wings column. Width and thick of wings, strength of concrete, and the steel content of wings of the experiments were the four main parameters in this test. In this paper experimental research not only investigated "total" lateral deflection but also resolved component of bending deflection and shear deflection. The theoretical researches, besides applying constitutive laws of concrete and rebar, semi-rigidity model and moderated softening mode approaches to solve shear and bending of wing column was proposed. Finally, the effect of strength of concrete and width of wing to affect the wing column was confirmed. As a result, the rigidity model of RC wing column was established. The width scale dominates the strength of the RC wing column. The strength ratio of column with wings to column is proportion to the ratio of width of the wing scale to the column width, and the ratio value is about 2 when the condition of wing thick to column width being 1/2. In the same way, the strength ratio will arise to 3 when the ratio of wing thick to column width being 3/4.

### SHAKING TABLE TESTS ON AN ASYMMETRIC LIMESTONE MASONRY BUILDING – ID 536

*R. Bairrao, LNEC, Portugal*
*E. Coelho, LNEC, Portugal*
*A. Campos Costa, LNEC, Portugal*
*M. J. Falcão Silva, LNEC, Portugal*
*E. Juhasova, Slovak Academy of Sciences, Slovakia (Slovak Republic)*

This paper will describe the shaking table tests of an asymmetric limestone masonry building, under different reinforcement conditions. The work was performed in the aim of the project “Enhancing Seismic Resistance and Durability of Natural Masonry Stone” for User Group 3 of the European Consortium of Laboratories for Earthquake and Dynamic Experimental Research (ECOLEADER). The experimental program was performed using the LNEC 3D shaking table.

For the first phase of the tests the specimen was just horizontally reinforced with polymeric grids. For the second phase it was also vertically confined with polymeric grids and with a fiber added mortar. The design of the structure was a common decision of the specialists involved from the University of Bucharest, the Slovak Academy of Sciences and the IRIDEX Construction Group, on the basis of an architectural conception typical of the buildings under study as well as on pre-existing buildings in Romania. The construction was operated and supervised in the LNEC earthquake-testing hall.

The construction of the specimen, its reinforcement, the testing procedure and the main testing results will be presented. The geometry and the materials chosen and the construction procedure will be detailed as well as the instrumentation and the different input signals adopted. Finally, the main damages observed will be shown.

These tests had as main purpose the evaluation of the behaviour of new and rehabilitated natural limestone masonry structures reinforced with polymer grids produced in the European Union.

### QUASI-STATIC TESTS ON WALL ELEMENTS CONSTRUCTED DURING THE RECONSTRUCTION OF ST. ATHANASIUS CHURCH – ID 538

*V. Sendova, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*
*M. Velkov, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*

The church of St. Athanasius is situated within the monastic compound St. Bogoroditsa in the village of Leshok - Tetovo area. This church is under the protection of the Law on Protection of Cultural Monuments of R. Macedonia. On August 21, 2001, during the armed conflicts in R. Macedonia, this monastic church experienced strong detonation which resulted in its almost complete demolition: a greater part of the church was torn down, while the still existing part was characterized by severe damage.

The Main Project on the Reconstruction of the Monastic Church of St. Athanasius has been realized by the Institute of Earthquake Engineering and Engineering Seismology, IZIIS in collaboration with the Republic Institute for Protection of Cultural Monuments and has been financed by the European Agency for Reconstruction.

The analyses used as a basis for the elaboration of the structural solution for reconstruction of the church were carried out by consideration of design compressive strength of lime mortar of 1.0 MPa. In order to achieve the designed class of lime mortar, the job mix formula for lime mortar included not only slaked lime and sand with a certain grain size distribution, but also broken half-baked brick as an additive in the corresponding proportion.

To verify experimentally the design strength characteristics of lime mortar, quasi-static tests on wall elements were carried out in the Dynamic Testing Laboratory of IZIIS in accordance with the previously adopted testing programme and scheme and the corresponding age of the wall elements. The wall elements were constructed in the same way as the original bearing walls of the St. Athanasius church structure in Leshok. The paper presents the objective, the procedure and the results from these experimental quasi-static tests.

### AMBIENT VIBRATION TESTING OF HISTORICAL MONUMENTS – ID 543

*L. Krstevska, Institute of earthquake Engineering-IZIIS, Macedonia*
*L. Taskov, Institute of earthquake Engineering-IZIIS, Macedonia*

To evaluate the seismic behavior of historical monuments, most of which have been damaged and restored in the past, one of several important aspects that should be considered is definition of the actual state of the monuments, i.e. obtaining of their dynamic characteristics by means of natural frequencies, shapes of vibration, damping coefficients and soil-structure interaction. In the frames of the bi-lateral Turkey-Macedonia cooperative project entitled "Evaluation of Seismic Safety of Historical Masonry Monuments", realized by the following institutions: Yildiz University- Faculty of Civil Engineering and Architecture, Istanbul and University "Ss. Cyril and Methodius"- Institute of Earthquake Engineering and Engineering Seismology-Skopje, experimentally tested were nine monuments - mosques and churches in Turkey and Macedonia. The in-situ experimental testing of the monuments was performed applying the ambient vibration testing method and an appropriate testing equipment. In order to define the dynamic behaviour of the monuments, the following dynamic properties were measured: natural frequencies, mode shapes and damping coefficients. The natural frequencies were evaluated from the Fourier amplitude spectra for both translational directions and torsion. The mode shapes were derived from the peak amplitudes of the spectra at corresponding measuring points along the height of the structures. The obtained results will be presented in the paper.

### SHAKING TABLE TEST OF 1/3 SCALE MODEL OF PIPELINE SYSTEM - PART 1:EXPERIMENTAL RESULTS – ID 548

*L. Tashkov, Institute of earthquake Engineering-IZIIS, Macedonia*
*L. Krstevska, Institute of earthquake Engineering-IZIIS, Macedonia*
*V. Hristovski, Institute of earthquake Engineering-IZIIS, Macedonia*
*B. Temelkovska, REK OSLOMEJ, Malawi*

The pipeline systems play an important role in proper functioning of the integral system for production of electricity at thermal power plant (TPP). To increase the exploration period as well safety factor of the pipeline systems, it is necessary to investigate the restraining conditions (spring hanging and supports) under dynamic and seismic loading. Up today practice in investigation of dynamic behavior of the pipeline systems at TPP is based on analytical approach, using refined finite element concept. Very few investigations are performed on experimental way, such as: in situ testing of dynamic characteristics by means of ambient and forced vibration method, as well as laboratory testing by means of shaking table. In this paper are presented experimental results obtained by model testing of a segment of pipeline system at TPP, designed and constructed in scale 1/3, and tested on seismic shaking table at IZIIS laboratory. The adopted modeling concept was: adequate model with artificial mass simulation, using the same material as prototype. The spring hanging as well as special rolling supports have been also simulated. The model was subjected to random, harmonic and earthquake motion in horizontal, vertical and biaxial direction. The test results show clear picture about dynamic behavior of the system under different excitations. Very interesting conclusions have been derived regarding springs behavior as well as rolling supports under earthqauke simulation tests.

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### COMPARISON OF EXPERIMENTAL AND FINITE ELEMENT RESPONSES OF STEEL-FIBER-REINFORCED CONCRETE BEAMS – ID 587

*D. M. Ozcan, Karadeniz Technical University, Turkey*
*A. Bayraktar, Karadeniz Technical University, Turkey*
*S. Adanur, Karadeniz Technical University, Turkey*
*T. Haktanir, Erciyes University, Turkey*

Steel fiber reinforced concrete (SFRC) applications have become widespread in such areas as highway upper layers, tunnel shells, concrete sewer pipes, and slabs of large industrial buildings. Usage of SFRC in load-carrying members of buildings having conventional reinforced-concrete (RC) frames is also gaining popularity recently because of its positive contribution to both energy absorption capacity and concrete strength.

In this study, a comparative study of flexural behaviors of the same dimensions ordinary and SFRC beams are carried out by experimentally and finite element method (FEM). For this purpose, three rectangular RC beams of 250x350x2000 mm dimensions and three SFRC beams of the same dimensions are produced using a concrete class of C-20, all the six beams having the same amount of reinforcement bars and all being designed as under-reinforced. Each of these six beams are subjected to bending by a three-point loading setup in certified beam-loading frame, exactly after having been moist-cured for 28 days. Each beam is loaded until full failure and the loading is stopped when the tensile steel bars are broken into two pieces. Mid-section deflections and loads are carefully recorded at every 5 kN load increments from the beginning till the ultimate failure. The flexural behaviors of the conventional RC beams and the SFRC beams are analyzed comparatively. The FEM results are obtained using the program SAP2000. The RC and SFRC beams are represented by two dimensional finite elements.

High energy absorption capacity of flexural elements is particularly important for resistance against earthquake loads. It is concluded herein that SFRC beams would exhibit a more effective performance than ordinary RC beams from this aspect.

Key Words: Reinforced-Concrete (RC) Beam, Steel-Fiber-Reinforced Concrete (SFRC), Energy Absorption Capacity (Toughness), SFRC Beam, Finite Element Method (FEM)

### INSTRUMENTAL DATA AND ANALYTICAL CONSIDERATIONS ON THE PERFORMANCE OF A PECULIAR STRUCTURE – ID 598

*I. Vlad, TUCEB, Romania*
*M. N. Vlad, TUCEB, Romania*
*H. Sandi, TUCEB, Romania*

The paper presents the outcome of some analyses concerning the performance of a seven-storey structure, having a peculiar configuration: the earthquake resistant system consists essentially of three strong cores arranged in plan as an equilateral triangle (one of them, taller than the other two). The object of the paper is related to the presentation of some methodological aspects and of some results concerning the dynamic characteristics and the resistance capacity of the structure referred to. The data on linear dynamic characteristics were obtained on the basis of monitoring the ambient vibration of the structure. The arrangement of seismometers and the basic relations used to pass from primary instrumental data to data on the relevant dynamic charateristics (overall bending, overall torsion, vertical motions) are presented. The input records were accordingly converted and data on the natural periods and on the eigenshapes were derived by means of corresponding transformations. Samples of time histories obtained are presented and the influence of the lack of perfect symmetry, due to the existence of one taller resistant core, is discussed. Some results of conventional engineering analyses are presented. A discussion on the capability to resist very high seismic intensities follows. The cores are sufficiently strong to resist overall bending moments and shear forces up to the level of loading when partial uplift of the core foundations occurs, limiting thus the possible stresses. It turns out that the main resistant system is practically immune to earthquakes and that local, little relevant, damage can occur only due to the (angular) relative displacements between main cores and the rest of the structure. A final summary emphasizes the methodological aspects raised by this case study and formulates some recommendations for engineering practice.

### EXPERIMENTAL RESEARCH ON LOW-REINFORCED CONCRETE WALLS – ID 643

*M. Pavel, National Centre for Seismic Risk Reduction, Romania*
*M. Seki, National Centre for Seismic Risk Reduction, Romania*
*C. Pavel, National Centre for Seismic Risk Reduction, Romania*
*R. Vacareanu, National Centre for Seismic Risk Reduction, Romania*

Within the Japanese-Romanian Cooperation Program on Reducing Seismic Risk of Buildings and Structures, established in 2002, various tests of RC and masonry elements were carried out. These tests aimed to simulate the behavior of existing buildings, especially those built prior to the great Vrancea earthquake of 1977, March 4 (M=7.2). Before 1977, buildings were realized using a seismic code which is thought now to be a "low-code". Retrofitting of them is a matter of great importance today, and experimental research data can be a valuable tool in evaluation and retrofitting. Outline of the tests consist of 5 RC wall specimens, with dimensions 1.80 m (length), 1.80 (height), 0.10 m (thickness). The geometrical dimensions were obtained by scaling two stories of a 10-stories residential building constructed in the 70's, in Bucharest. Scale factor was $\frac{1}{4}$. The specimens were tested using the testing facilities (reaction frame) provided by JICA (Japanese International Cooperation Agency). Load was applied vertically (constant vertical load – simulating the gravitational load level in the existing building) and horizontally (cycling loads – 2 cycles at every peak displacement). Typical reinforcing for the specimens (used extensively in RC walls before 1977) is: vertical round bars at walls intersections, horizontal bars below the slab and in the slab, leaving the concrete web unreinforced. This pattern of reinforcing is now forbidden by new design codes. For each specimen, prediction of capacity was performed using various design codes and compared with the experimental results.

### SHAKE TABLE TESTS OF A 3-STOREY IRREGULAR RC STRUCTURE WITHOUT ENGINEERED EARTHQUAKE RESISTANCE – ID 645

*E. Coelho, LNEC, Portugal*
*A. Campos Costa, LNEC, Portugal*
*P. Candeias, LNEC, Portugal*
*M. J. Falcão Silva, LNEC, Portugal*

With the purpose of assessing the seismic behaviour of a reinforced concrete building structure non-seismically designed, an experimental study was carried out at the LNEC/Lisbon shake table, within the framework of the European project SPEAR. The tested structure was a simplification of a 3-storey building, irregular in plan, representative of older construction in southern Europe, without engineered earthquake resistance. It was designed for gravity loads alone, using the concrete design code used in Greece between 1954 and 1995, with construction practice and materials commonly used in southern Europe in the early 70's. The structural configuration is typical of non-earthquake-resistant construction of that period. The centre of stiffness is eccentric with respect to the mass centre in both horizontal directions and the configuration includes two beam indirect supports and a strongly eccentric beam-column joint. The Lisbon specimen was built in a 1:2,5 scale and tested under a seismic excitation representative of the Montenegro 1979 earthquake. Two horizontal motions were applied to the specimen by the shake table in both directions. Semi-artificial input series were used, obtained from the modification of the two Herceg Novi horizontal components of the earthquake, in order to satisfy conformity with the Eurocode 8 elastic response spectrum. No vertical excitation was considered. In order to measure the experimental response of the model, the signals acquisition was achieved through the use of a specific instrumentation plan consisting on accelerometers and displacement transducers, allowing the evaluation of the complete global motion of the structure. The paper presents the main experimental results obtained and illustrates its comparison with pre-test analytical simulations. Furthermore the comparison with the results of a real scale test of the same structure, performed at the ELSA laboratory in Ispra, is outlined.

### EXPERIMENTAL MODAL ANALYSIS OF THE CEDRAV HISTORICAL BUILDING – ID 646

*D. Rinaldis, ENEA, Italy*
*P. Clemente, ENEA, Italy*
*G. Teresi, ENEA, Italy*

The CEDRAV building in Cerreto di Spoleto (Centre for Anthropological Documentation and Research of Nerina Valley building), originally a monastery, was built in the 14th century on the top of a ridge rock. The building is irregular both horizontally and vertically. The ambient vibration measurements were performed by using fifteen SS-1 uniaxial velocity sensors (natural frequency 1.0 Hz) connected to five K-2 recorders. Measurements were carried out between May 2000. Sensors were deployed in 9 different configurations. Then the building was permanently instrumented in June 2000 by using 36 accelerometer channels. Transducers have been installed in different locations of the structure. In particular, some of these have been arranged on the perimeter walls to obtain torsional modes of the structure. In this work the results of the experimental investigations on the CEDRAV building in Cerreto di Spoleto are explained together with the following numerical elaborations of the picked data. On the base of recorded data a preliminary analysis in frequency domain, based on the determination of auto and cross power spectral density, has been made; subsequently it has been proceeded to the modal structure's identification through the use of Ibrahim technique, working in the time domain, and through Frequency Domain Decomposition technique, working in the frequency domain. A frequency domain analysis of the structure has been performed by means of a Frequency Response Function (FRF), that is the ratio between output and input Fourier transforms. The frequencies and the modal shapes experimentally obtained has subsequently been object of comparison with the same quantities calculated through a finite element model.

### PSD TESTS AND SUBSTRUCTURING OF DAMAGEABLE STRUCTURES UNDER TWO COMPONENT EARTHQUAKES. – ID 676

*A. Souid, LMT-CACHAN., France*
*A. Delaplace, LMT-CACHAN., France*
*F. Ragueneau, LMT-CACHAN., France*
*R. Desmorat, LMT-CACHAN., France*

The comprehension of the ultimate behavior of Civil Engineering structures subjected to natural or industrial risks such as shocks, impacts, seisms, explosions ...etc can be handled by two ways: experimental testing and numerical modeling. By using the recently developed nonlinear material models in the analyses, one can better apprehends the response of the structures. A combination between the numerical modeling (into which one can introduce the suitable model of material behavior) and a test on parts of the structures can be made to better understand the structure response while benefiting from the substructuring technique. To numerically determine the inertia forces for performing static tests instead of dynamic ones leads to the so-called pseudo-dynamics (PSD) modelling. We describe and present the results for such PSD tests with substructuring technique carried out in nonlinear behaviour. The tests were conducted for a two level reinforced concrete frame which is subjected to a real two components earthquake (horizontal and vertical). We present the use of computations for the modelized and tested sub-structures in the PSD tests. An implicit and explicit time integration schemes are used for the simulated parts in parallel with an explicit one used for the tested part. Tests results are used to identify and validate the nonlinear constitutive equations used. For instance, a three dimensional damage model with induced damage anisotropy is described and used for quasi-brittle materials such as concrete. A single 2nd order tensorial damage variable is considered. The quasi-unilateral conditions are written on the hydrostatic stresses only. Note that altogether with the consideration of damage laws ensuring a damage rate proportional to the positive part of strain tensor, this is sufficient to model a strongly different behavior due to damage in tension and in compression.

Keywords : PSeudo Dynamics tests (PSD), earthquake engineering, substructuring, anisotropic damage.

### FRICTIONAL APPROACH TO SEISMIC ANALYSIS OF FLEXIBLE SLIDING-STRUCTURES – ID 682

*B. Mendez, Institute of Engineering, UNAM, Mexico*
*E. Botero, Institute of Engineering, UNAM, Mexico*
*M. Romo, Institute of Engineering, UNAM, Mexico*

A seismically-excited 3DOF experimental model sliding down the inclined plane of a shaking table was instrumented with an LVDT and accelerometers to measure its dynamic response to harmonic excitations. Based on laboratory measurements, friction coefficient variation and its correspondent transition from coupled to sliding conditions were characterized into a continuous friction law. This law was used to compute the 3DOF model's base acceleration time history response. Its flexibility was accounted for using experimental constants in the friction law advanced in this paper. The computed base-acceleration is then used as the input motion in a dynamic analysis. The model response was also computed using Coulomb's friction law, to show the influence of friction variation in model response, which is presented in terms of accelerations and frequency content. The numerical results were compared to experimental measurements showing good agreement when using the friction law proposed here, thus concluding that the approach developed in this study can be used as a decoupled analysis procedure to analyze flexible sliding-structures, such as friction base-isolated buildings.

### TESTING OF AN ELEVATED VIADUCT IN MEXICO CITY – ID 695

*D. Murià-Vila, Instituto de Ingeniería, UNAM, Mexico*

*A. R. Sánchez-Ramírez, Instituto de Ingeniería, UNAM, Mexico*
*R. Gomez Martínez, Instituto de Ingeniería, UNAM, Mexico*
*J. A. Escobar-Sánchez, Instituto de Ingeniería, UNAM, Mexico*

The Institute of Engineering of UNAM carried out a series of experimental tests on an elevated viaduct which will help to alleviate one of the busiest traffic expressways of the city. The overall project included the construction of two and three lanes superstructures of the Gerber type with a total length of 13 km. The viaduct is composed of prestressed concrete box girders supported on piers founded on footings supported on four circular piles. Structural configurations proposed by the designer for the two and three lanes segments of the viaduct are different. The first one uses concrete reinforced piers with large precast and prestressed girders, whereas the second one uses precast and prestressed columns, and prestressed girders composed of several elements which are assembled in situ.

Because of the importance of the structure and the well known seismic risk of structures in Mexico City, a special experimental field program, comprising ambient vibration, lateral loads and loadings produced by special trucks, was proposed to measure the response of the structure. The purpose of the testing was to identify some mechanical properties of the viaduct, to corroborate some basic seismic design hypothesis, and to discover possible discrepancies that could affect the structural safety of elevated expressways, currently under construction in Mexico City, and particularly to define the need of some adjustments for future works of the type.

In order to measure lateral deflections, stiffness and tilting of the piers, lateral loading tests comprised the application of a nearly horizontal load on the top of a pier. Evaluation of the special provisions of reinforcement placed between the footing and the column of the pier was also carried out. A crane of 550t capacity was used to apply an increasing monotonic load up to 71t.

## RECORDED SEISMIC RESPONSE OF AN INSTRUMENTED HIGH-RISE REINFORCED-CONCRETE BUILDING IN BUCHAREST – ID 777

*S. Demetriu, UTCB/NCSRR, Romania*
*A. Aldea, UTCB/NCSRR, Romania*

The National Center for Seismic Risk Reduction (NCSRR, Bucharest, Romania) instrumented in 2003 a modern bank headquarter RC building in Bucharest. This high-rise building has a dual reinforced concrete structure (inner shear wall tube and perimeter frame), with 3 under ground stories, ground floor and 18 stories above ground. With it's 74m it is the second tallest building in Bucharest. The building was designed and erected in 2001-2003. The seismic instrumentation (donated by Japan International Cooperation Agency) consists of one seismic station with two tri-axial sensors for acceleration, one located at the top of the building and the other one on the foundation slab (third under ground storey). At about 150m near the building another seismic station was installed by NCSRR, with triaxial sensors at ground surface and in two boreholes at 30m and 151m depth. The building's dynamic characteristics are estimated using the recorded data from eight moderate earthquakes (with moment magnitude Mw ranging from 3.9 to 5.1) and a moderate earthquake (Mw=6), events that occurred in 2004 and 2005. All these earthquakes are from the Vrancea subcrustal source (focal depth between 70-170km) located at about 150 km hypocentral distance from the building site. The paper also presents the analysis of simultaneous recorded data during the May 14th, 2005 earthquake (Mw=5.1), obtained at both seismic stations (i.e., in building and in free-field & boreholes).The results obtained from earthquake response data are compared with those from ambient vibration measurements.

## CHARACTERIZATION OF A LARGE SHAKING TABLE FACILITY AT EUCENTRE PAVIA – ID 778

*T. Trombetti, DISTART - Università di Bologna, Italy*
*A. Pavese, DMS - Università di Pavia, Italy*

This paper reports on the tests performed in order to characterize the dynamic properties of a large shaking table facility recently installed at EUCENTRE, European Centre for Training and Research in Earthquake Engineering (Pavia, Italy). The shaking table (characterized by a single horizontal degree of freedom) is hydraulically powered, has a rectangular platen of about 5.6 by 7 meters in plan and can perform dynamic tests on specimen up to 140 ton in weight (maximum overturning moment of 400 ton meter). The maximum table displacement is +/- 0.50 m, the maximum table velocity is 2.2 m/sec and the maximum table acceleration (for bare table conditions) is about 6.0 g. The table shows an innovative design which is characterized by a reaction mass of 2225 ton, about 64 time the mass of the platen which, in order to react effectively against the inertia forces induced by the motion of the platen, uses of the soil surrounding the table foundation. The test performed allowed to characterize and verify some of the fundamental properties of the system: (a) the effective horizontal displaced mass of the table platen, (b) the dynamic properties of the platen itself (modal frequencies and deformations), (c) the forces requested to move the table when no inertia effects are to be accounted for (frictional and dissipative forces), (d) the maximum table performances (maximum displacement, velocity and acceleration) obtained for the table. The main object of this study is to calibrate a theoretical model previously developed for smaller and less powerful system to the table of EUCENTRE, the merit of such a model is to make easier the prediction of the effective performance when applying seismic input to large specimens and testing them to the collapse limit

## COMPAIR OF DYNAMIC SPECIFICATIONS IN MATHEMATICAL MODELS WITH TEST OVER REAL MODELS – ID 782

*A. Arash Sayari, IAU of Sanadaj, Iran (Islamic Republic Of)*

Considering "dynamic specifications of constructions including natural vibrating periods, modes and amount of damping" of mathematical and theoretical models with respect to the Fact that simplifying approaches are used in them and the impact of non-constructions components are ignored, and as amount of damping in constructions which is based on the kind of these materials being used and the style of construction, the accuracy of these models should be examined on construction materials by shaking tests. In order to detect co-ordination gained from mathematical and theoretical Models with real tests, construction models for buildings with steel structure first mathematically analyzed, and then, it has been put under Steady- state sinusoidal Excitation. Records from building's response have been attained in all directions and all frequencies being stimulated by shaker set, and response has been drawn after processing the records. Paying attention to these spectra as well as rate of responses and difference in Accelerometer's phase the difference in each intensive frequency, modes for changing from of building has been drawn. Mode damping, also, has been gain from each mode by using half band method in response spectra. Results from analysis and test have been compared it's been tried to modify the mathematical model in such a way that its results are conformed to those of the test. First computer modeling has been ignored because of stiffness of infill walls, and so, there was a significant difference between mathematical and computerized models. After modeling the stiffness of infill walls in computer model, there are respondent between mathematical and computerized model. Comparing mathematical and computerized results, its been specified that infill walls have basic roies in the behavior of construction and it's hardness should be considered in computerized analysis.

## A SUBSTRUCTURE HYBRID EXPERIMENT OF A SEMI-ACTIVELY CONTROLLED BASE ISOLATED BUILDING – ID 881

*H. Iemura, Kyoto University, Japan*
*A. Igarashi, Kyoto University, Japan*
*A. Kalantari, Kyoto University, Japan*

This study focuses on performing a real time substruc-

ture hybrid experiment of a semi-actively controlled base isolated building using an Inertia Force Driven Loading (IFDL) device and a variable oil damper. In a real time substructure experiment, the structure is split into a physical and a numerically modeled structure, which interact in real time allowing time-dependent nonlinear behavior of physical specimen to be accurately measured. In this research, as the physical part, a variable oil damper is used and the simultaneous control of the IFDL and the variable oil damper is performed. The IFDL device has been developed in previous studies to characterize the performance of dampers and energy dissipation devices under the loading condition. It is composed of an elastically supported main mass and a mass-driver device installed on the main mass. The variable damper is assumed to be installed in a base isolated building idealized by a single-degree-of-freedom model as well as a multi-degree-of-freedom model as the numerical part. During the experiment, the IFDL device realizes the structural response resulted from numerical part and applies it to the variable damper. The damping control force is then measured and sent to the controller computer for the next step. The experiment is carried out using a harmonic loading as well as ground motion records of El Centro and Kobe earthquakes. Using this system, the performance of the variable oil damper under the control algorithms is evaluated during the excitation. Furthermore, the performance of the semi-active control of the modeled isolated structures is evaluated by employing skyhook algorithm as well as Pseudo Negative Stiffness algorithm, and the results are compared with the numerical simulations.

## DYNAMIC BEHAVIOUR OF THE FIRST INSTRUMENTED BUILDING IN FRANCE: THE GRENOBLE TOWN HALL – ID 941

*C. Michel, LGIT, University of Grenoble, France*
*P. Gueguen, LGIT, University of Grenoble, LCPC, France*

The French Accelerometric Network (RAP) launched in November 2004 a pilot scheme to assess the seismic behaviour of a typical French building. The main goal of this project was to collect accelerometric data in the building and then use them to calibrate models or alternative tools used for the seismic behaviour assessment. The final goal of this project is to help the vulnerability assessment of cities in moderate seismic hazard country. The RAP chose to install a permanent network of 6 accelerometers recording continuously the vibrations of the Grenoble Town Hall at the basement and at the top. The 13-story building is a RC shear walls building, typical of the RC structures designed at the end of the 60's in France. All the data collected in the building are available on the online access database of the RAP. In addition to the permanent network, an ambient vibration experiment has been performed in 36 points of the whole building. Using the Frequency Domain Decomposition method, these data allowed estimating precisely the different modes of vibration of the structure for low amplitudes. Only the first bending modes in each direction (1.15 and 1.22 Hz) and the first torsion mode (1,44 Hz) are excited. The building behaves almost like a cantilever beam. We compared the obtained frequencies with a (small) earthquake recorded by the permanent network and found only minor differences. Thanks to the continuous recording, a statistical approach of the torsion mode pointed out the position of the centre of rotation of the building. It is clearly shifted to the West that explains the torsional response of the structure. A modal model based on the ambient vibration survey is proposed and validated thanks to the earthquake recordings collected in the building during the ML=4.6, September 8th 2005 Vallorcine (Haute-Savoie, France) earthquake.

## STATIC AND DYNAMIC PROPERTIES OF THE SHAKING TABLE RECENTLY BUILT AT THE EUCENTRE, PAVIA – ID 967

*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*A. Pavese, Department of Structural Mechanics, Italy*

This paper reports on the first test performed in order to characterize the static and dynamic properties of the shaking table facility recently built at the EUCENTRE (European Center for Training and Research in Earthquake Engineering) in Pavia, Italy. The shaking table (characterized by a single degree of freedom) is hydraulically powered through a single actuator, and is characterized by a rectangular platten of about 6.8 by 3.5 meters in plan. The total dynamic stroke of the actuator is equal to 1000 mm ( +/- 500 mm), the maximum table velocity is 1.80 m/sec (for bare table condition) and the maximum table acceleration (for bare table conditions) is about 5.0 g. The table shows an innovative design which is characterized by hydraulic cushions (sized for 85v tones mass: table + specimen) capable of providing both vertical support and clamping against overturning and jaw motion. The test performed allowed to characterize and verify: (a) the effective horizontal mass of the table platten, (b) the dynamic properties of the platten itself (modal frequencies and deformations), (c) the forces necessary to move the table when no inertia effects are to be accounted for (frictional and dissipative forces), (d) the maximum table performances (maximum displacement, velocity and acceleration) obtained for the table, and (e) the capacity of the table in reproducing earthquake ground motion. The results obtained experimentally are compared with the theoretical predictions and show a good agreement. Also, the paper reports on the first test performed to evaluate the capacity of the table to reproduce dynamic signals (both sinusoidal and earthquake acceleration time histories type).

## RETROFITTING OF PRECAST COLUMNS – ID 971

*K. Taskin, Istanbul Technical University, Turkey*
*E. Yuksel, Istanbul Technical University, Turkey*
*P. Teymur Tuga, Istanbul Technical University, Turkey*
*F. Karadogan, Istanbul Technical University, Turkey*
*S. Z. Yuce, Istanbul Technical University, Turkey*
*N. Yardimci, Istanbul Technical University, Turkey*

The use of fiber reinforced polymer (FRP) for retrofitting of reinforced concrete (RC) structures has increased rapidly in recent years. FRP sheets are made of high strength continuous carbon aramid or glass fibers, which are impregnated with resin and have some excellent properties such as resistance that is high compared to its weight. In addition to FRP reinforcements, jacketing is also one of the mostly used strengthening methods. This study focuses on using a new technique of retrofitting of pre-damaged precast concrete columns (PPCC) by using FRP reinforcement and jacketing together. Four 1/1 scale damaged PPCC columns are retrofitted by this new technique. The test specimens are retrofitted by the same kind of FRP sheets and have the same application height of 2m. However, height of the RC jacket is 1m for two specimens and 2m for the others. They are tested under a constant vertical load with a cyclic lateral load. The cracks on the specimens, sectional rotations and lateral translations for different heights of the columns will be monitored during the tests. The test results will be compared with each other and a non-retrofitted column and a retrofitted column with only jacketing. It is expected that the lateral stiffness and lateral load capacity of the columns retrofitted with the proposed technique will be much larger than the others.

## STONECUTTERS CABLE-STAYED BRIDGE: FULL-SCALE TESTING OF DYNAMIC CONTROL DEVICES – ID 985

*G. P. Colato, FIP Industriale, Italy*
*R. Chiarotto, FIP Industriale, Italy*
*S. Infanti, FIP Industriale, Italy*

The Stonecutters cable-stayed bridge, now under construction, is a crossing 1600 m long characterized by an 1018 m main span that sets it amongst the longest bridges of this type. It is located in Hong Kong and is part of the local authority's new infrastructure development plan. This structure, both critical and strategically important is designed to withstand extreme wind storms and earthquakes. Thus, the designer's foresight contemplated using a non-conventional restraint system to connect the deck to the pylons in both the longitudinal and transverse directions. At each pylon, a group of four 8000 kN capacity (800

mm stroke) Shock Transmission Units (later on referred as STUs) are installed along the longitudinal direction, while two preloaded spherical bearings connect transversally the steel girder to the pylon - with a reaction that depends upon the dynamics of the imposed load. At the onset of any mentioned design dynamic action, the longitudinally acting units (STUs) are designed to temporary link the deck to the pylons providing for a very stiff connection. In order to avoid torque effects in the bridge structures, each group of units has a common hydraulic circuit that makes them react simultaneously during the dynamic event. Furthermore, said hydraulic circuit is designed to reduce to a minimum the reaction associated with slow movements induced by deck thermal expansions and prevent unexpected overloads. The special bearings reacting in the transverse direction are hydraulically preloaded and react as STUs only at the occurrence of a dynamically imposed load. This paper presents the technical description of the aforesaid units as well as related technologies with particular emphasis on the full-scale testing program performed in accordance to contractual specifications.

### SHAKING TABLE TESTS ON FULL-SCALE ONE STOREY R.C. INFILLED FRAME STRUCTURE – ID 992

*A. Le Maoult, CEA, France*
*E. Candigliota, Università « G. d'Annunzio » di Chieti, Italy*

This paper will describe the experimental work and present some main test results. Recent earthquakes, in Italy and Greece, confirmed that infilling panels represent an important source of both strength and damage in existing building whether designed or not to seismic action. As part of Ecoleader European research program, a frame was designed on the basis of an old Italian seismic code, with constructive details that adhere as much as possible to those of a class of real structures. This structure represents the first infilled floor of a two floors bare frame that has been preliminary tested during 2004. This mock up is a full-scale r.c. infilled frame structure with one storey (3 meters height), a 4.3 meters side square floor, four columns and a masonry infilled panel with double wall unity. Mono-directional and bi-directional seismic tests (reference spectrum issued from EC-8 spectrum, C-soil) on this model were conducted on shaking table at CEA Saclay (France) from September 2004 to January 2005. Objectives were to record real information about damages and strengths during a seismic solicitation. 3 successive configurations of the mock up have been tested: bare frame, infilled frame with 4 walls (with and without openings) and infilled frame with 2 walls (without openings). The high maximum ground acceleration applied (0.55 g) to the structure allowed to observe serious collapses on walls: two interior opening walls finally felt down due to the addition of in plane and out plane solicitations. On the other hand, collapses on the frame were moderate.

### EXPERIMENTAL STUDY ON REINFORCED CONCRETE JACKETED COLUMNS – ID 1017

*D. Cotofana, TUCE, Romania*
*V. Popa, TUCE, Romania*

The results presented in this paper are obtained from a test program for columns implemented in the TUCE / NCSRR, Structural Testing Laboratory. One objective of this experimental work is to study about the influence of the transversal and longitudinal reinforcement ratio on the ultimate displacement and shear capacity of reinforced concrete jacketed columns. The analyzed specimens represent the old buildings columns constructed before the implementation of the first Romanian seismic design code. These columns are characterized by a low ductility mainly due to the high intensity of axial load and the poor transversal reinforcement ratio (usually less than 0,001). A widely used procedure in Romania for retrofitting this type of columns is the reinforced concrete jacketing. The first specimen (A) represents the original old column. It is characterized by a rather low quality of concrete, with a mean strength of 20MPa, and an axial force ratio of 0.4 (computed using the mean compressive strength of concrete). The transversal reinforcement ratio is 0,001 and the longitudinal reinforcement ratio is 0,01. The second specimen was obtained by retrofitting specimen A. The shear reinforcement ratio has been increased from 0.001 to 0.006 while the flexural capacity has not been improved. The third specimen has been derived from specimen B by increasing the ratio of longitudinal reinforcement. The aim of this test was to investigate about the shear capacity of specimen B. A higher flexural capacity has been considered to obtain the shear failure. This paper presents test data and observations. The results obtained using some analytical procedures to evaluate the specimens' ultimate capacity and shear capacities are also presented.

### STEEL BEAM-COLUMN CONNECTION USING COPPER-BASED SHAPE MEMORY ALLOY DAMPERS – ID 1024

*O. Moroni, Universidad de Chile, Chile*
*J. Sepúlveda, Universidad de Chile, Chile*
*R. Herrera, Universidad de Chile, Chile*
*R. Boroschek, Universidad de Chile, Chile*
*M. Sarrazin, Universidad de Chile, Chile*

This study evaluates the feasibility of a partially restrained connection using copper-based shape memory alloy bars. The proposed connection consists of four CuAlBe (diameter=3 mm) prestressed bars, in austenitic phase, connecting a hollow rectangular beam to a column flange, that serves as the primary moment transfer mechanism. A scaled-model was tested applying a controlled sinusoidal displacement at the tip of the beam. The SAC loading protocol at 0.25 and 1 Hz was used. Potentiometers and load cells were used to measure strains and stresses in the bars and beam tip displacement and load. Similar bars, with the same thermal treatment, had been previously tested in tension at variable nominal strains and frequencies, showing superelastic behavior up to 2.3% strain. The equivalent damping ratio increases almost linearly for strains larger than 0.6%, being 4% for a 2.3% strain. In static tensile tests, the fracture strain was approximately 15%, with a transgranular fracture mechanism. The connection also exhibited superelastic behaviour, a moderate level of energy dissipation, large ductility capacity, and no strength degradation after being subjected to several cycles up to 4% drift.

### SHAKING TABLE TESTS OF 1:3 SCALE MODELS OF 4 STORIES URM BUILDINGS: MODEL ANALYSIS AND VULNERABILITY – ID 1081

*P. Candeias, LNEC, Portugal*
*E. Coelho, LNEC, Portugal*
*A. Campos Costa, LNEC, Portugal*

This paper will present the results obtained in the framework of an experimental programme carried at LNEC that aimed at the quantification of vulnerability curves of typical Portuguese old masonry buildings known as "gaioleiro" buildings, before and after reinforcement, adequate for global seismic risk assessment. The tests were performed in the LNEC 3D shaking table on 1:3 reduced scale models of 4 story unreinforced masonry buildings with masonry shear walls and wood-framed floors. The geometry of the models and materials used in their construction were chosen in order to simulate typical buildings.

The experimental tests will be described and the reinforcement schemes, as well as the reasons behind their selection, will be summarized. The experimental results to be presented will include the identification of dynamic parameters, such as vibration modes and frequencies, and their evolution during the several test phases, as well as a description of the collapse modes observed. Also some preliminary conclusions of the study, namely the efficiency of the reinforcement and the vulnerability curves, will be outlined.

### SHAKING TABLE TESTS OF HALF-SCALE MODELS MADE OF HAND MADE SOLID CLAY BRICKS – ID 1147

*R. Barragán, Mexico*
*S. Alcocer, Institute of Engineering at UNAM, Mexico*
*G. Arias, Colombia*

In order to evaluate the dynamic behavior of housing buildings made of confined masonry in México, a series of shaking-table tests of small-scale models are currently underway at the Institute of Engineering at UNAM. The dynamic response of one- two- and three-story model is discussed. The specimens were half-scale models made of hand-made solid clay bricks. The models were subjected to a series of seismic motions typical of the epicentral region along the Mexican Pacific. From test results and observations made, resistant mechanisms were identified. Structural capacity was evaluated in terms of strength, stiffness, deformation capacity and energy dissipation. The experimental response was compared to shaking-table tests of one- and three-story models. The model responses showed that buildings designed according to the Mexican codes are able to sustain relatively high dynamic excitations due to a significant level of structural overstrength.

## TIME-FREQUENCY ANALYSIS OF VRANCEA EARTHQUAKE RECORDS FROM INSTRUMENTED BUILDINGS – ID 1153

*S. Demetriu, UTCB/NCSRR, Romania*
*I. S. Borcia, INCERC, Romania*

During the Vrancea intermediate depth strong earthquakes of August 30, 1986 (Mw=7.2), of May 30, 1990 (Mw = 6.9) and of May 31, 1990 (Mw=6.3) several strong motions were recorded from nine instrumented multistory buildings of the INCERC seismic network located in different site conditions. A database containing the main characteristics of the reinforced concrete instrumented buildings in Romania and the seismic translational response records was created. The database includes absolute acceleration, velocity and displacement components on three orthogonal directions of motions at the base and at the top of buildings. Earthquake nonstationary structural records are multi-resolution analyzed using time-frequency methods and time-scale wavelet methods. The jointly energy distributions describe time-varying frequency content of the recorded seismic signals. These non-parametric time-frequency distributions were used to detect variations in the modal parameters of the instrumented structures. Interpretation of recorded large-amplitude seismic response will provide a useful tool for post-earthquake integrity assessment of existing structures. Identification of the dynamic characteristics of instrumented buildings is essential in assessing their seismic vulnerability.

## FINITE ELEMENT MODAL UPDATING OF REINFORCE CONCRETE BUILDING – ID 1186

*K. Azer, Ondokuz Mayis University, Turkey*
*T. Sertac, Ondokuz Mayis University, Turkey*
*U. Aysenur, Ondokuz Mayis University, Turkey*

This paper presents the results of monitoring 11 story reinforced concrete building. Dynamic characteristics were determined by analyzing ambient vibrations of the structure. The natural frequencies and their associated mode shapes were determined using frequency-domain and time-domain techniques. Finite element model of the building was evaluated. The experimental details and data-processing techniques are described. The output-only modal identification results were used to update a finite element model of the building. Parameters of the starting finite element model were modified using an automated procedure to improve the correlation between measured and calculated modal parameters. All of devises with appropriate software and necessary instruments for structural monitoring are placed in mobile vehicle designed by our department and use as mobile structural monitoring system (www.omu.edu.tr azer).

## SEISMIC REHABILITATION OF REINFORCED CONCRETE COLUMNS – ID 1210

*P. Rocha, Instituto Politécnico de Viana do Castelo, Portugal*
*P. Delgado, Instituto Politécnico de Viana do Castelo, Portugal*
*V. Rodrigues, Faculdade de Engenharia da Universidade do Porto, Portugal*
*M. Santos, STAP, Portugal*
*A. Arêde, Faculdade de Engenharia da Universidade do Porto, Portugal*
*N. Vila Pouca, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*
*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*

The main purpose of this paper is to present an experimental campaign of different strategies for the seismic retrofit of RC columns, comparing the obtained results with analytical methodologies, and evaluating benefits concerning their structural behaviour under the cyclic loading. The experimental campaign was conceived taking into account the typical constructions of the seventies, designed according to old codes without seismic considerations, and seeking the best structural retrofit technique to enable seismic behaviour improvement with acceptable financial resources. The setup of the RC columns experimental tests was specially designed to carry out biaxial bending with axial load, using two orthogonal and horizontal actuators and one vertical actuator (with a slide device to allow the top displacements of the column), though, at this stage, only uni-axial bending experimental results are available. The columns rehabilitation, improving the ductility or the strength characteristics, was obtained increasing the concrete ductility conditions, through efficient jacketing, or increasing the amount of longitudinal and transversal steel. The numerical simulation of the tests, as well as the application of a non-linear dynamic analysis methodology to evaluate the columns behaviour and the safety improvement of the various retrofit techniques adopted, is presented. The numerical seismic assessment of the tested reinforced concrete column was performed using a model with non-linear behavior concentrated in plastic hinges. The aim is, therefore, to contribute for developing and calibrating a procedure that enables the evaluation of the efficiency of the different retrofit solutions, their possibilities and fields of application. It was also an objective of this work to explore the possibility of use this retrofitting tecniques on the improvement of buildings performance.

## EXPERIMENTAL STUDY ON SHAPE MEMORY ALLOYS AS PASSIVE STRUCTURAL CONTROL SYSTEMS – ID 1213

*J. Fuentes, Engineering Institute, National University of Mexi, Mexico*

OBJECTIVE. It is described an experimental and analytical research conducted in shape memory alloys bars (SMA). The focus is to use this kind of materials as seismic energy dissipating devices (EDD). Fundamental concepts related to those materials are exposed briefly to understand their behavior according to its phase: shape memory phenomena in the martensitic phase and superelasticity phenomena in the austenitic phase. In a particular, the Cu-Al-Be SMA obtained at the National University of Mexico (UNAM) is analyzed. A seismic EDD for steel connections is proposed and simulated by means of Finite Element Method (FEM).

SCOPE. The scope of this work is: first, to explain the background of the SMA in an engineering point of view; second, show the results obtained through laboratory tests and finally, to propose an EDD for steel connections.

METHODOLOGY. The alloy is obtained through a smelting process in an induction furnace. Once the material is solidified, several specimens are analyzed by means of different techniques (DSC, X-rays, atomic force microscopy); as well as mechanical test (tension and uniaxial cyclic loading). Within the microstructural characterization several properties are obtained: grain size, present phases, transformation temperatures (Ms, Mf, As, Af) and critical transformation stresses. The following properties are obtained from the mechanical tests: Young's modulus, "pseudoflow" stress, Poisson's ratio, rigidity post-flow and hysteretic curves. Finally, it is made an

analytical study by Finite-Element-Method in order to simulate the SMA behavior.

CONCLUSIONS. The stress-strain curves found in this study show that the alloy has good possibility to be used as EDD because of its properties: shape memory to dissipate energy (wide hysteresis curves) and superelasticity to recenter (high stress values). The application of the SMA in seismic engineering is relatively new and represents a good opportunity to be used as part of passive vibration control of structures.

### DYNAMIC TESTS OF EXPERIMENTAL FRAGMENTS OF MULTISTORY BUILDINGS DESIGNED WITH METAL BRACED FRAMES – ID 1302

*A. Shakhnovich, Kazakh Research and Design Institute of Earthquake, Kazakhstan*
*I. Itskov, Kazakh Research and Design Institute of Earthquake, Kazakhstan*
*M. Wainstein, EMK Ltd, Kazakhstan*

The Technical solutions were developed and dynamic testing of a two-tier experimental fragment was carried out by experts from Kazakh Research and Design Institute on Earthquake Engineering together with the employees from 'EMK' Ltd. The constructive system of a 25-storey building, with metal frame which was applied in the tested experimental fragment has been designed for construction in Almaty region with 9-grade seismicity. The distinctive peculiarity of the design solutions is the application in frame system of a building of I-shaped cross section intermediate racks located on an external contour of a building between girts of a frame. During experimental construction testing with the help of shaker B-2, installed on the roof covering, in the level of experimental fragment weights' arrangement, the horizontal inertial forces were induced. The peak value of these forces corresponds to resonance state, under coincidence of the shaker's forced vibration frequencies with natural oscillations of constructive system . The quantitative characteristics of dynamic parameters and parameters of elastic-plastic condition of frame elements were registered in a mode of real time, with application of digital and analogue measuring complexes, on the basis of high-speed computing systems. Elastic-plastic condition of the constructive system which was revealed under excitation of resonant vibrations conforms with designed preconditions regarding outstripping formation of plastic deformation zones in basic sections of girts and in bracing elements of frame (in intermediate racks) at preservation of elastic behavior of elements ensuring general stability of the system (columns of frame). The constructive system under consideration has a high degree of plastic deformability which is characterized by perception of no less than 60-65 cycles of reversed dynamic loading with forces at the zone of plastic deformations which reach values of yielding flow dynamic limit

### REINFORCED CONCRETE WALLS' RESISTANCE TO IMPACT OF LATERAL SEISMIC LOADS – ID 1310

*M. Sholpanbaev, Kazakh Research and Design Institute of Earthquake, Kazakhstan*
*A. Bespaev, Kazakh Research and Design Institute of Earthquake, Kazakhstan*

The experimental and theoretical research of strength, cracking resistance and rigidity capacities, as well as distribution of forces of monolithic reinforced concrete walls under horizontal loading have been implemented for studying strained condition of reinforced concrete walls subjected to joint impact of both vertical and horizontal loads. The experimental specimen imitated ratio of forces within walls of 12-storey residential building designed for 9-grade seismicity. Four series of wall specimens with I-shaped cross section differed by reinforcement of peripheral zone, reinforcement in field and openings availability. Testing was performed at jamming of the bottom shelf in power testing stand and simultaneous loading by regularly distributed vertical load and horizontal force directed along the specimen and applied at the level of the top shelf. The loading was induced by means of hydraulic jacks of double action and hydraulic-dynamic plant MVG-1. Cyclic loading was carried out with frequency of 0.5-1.0 hertz and coefficient of vertical loading change asymmetry at about 0. The number of repeated loading at given amplitude of forces made up about 50 cycles, after that the amplitude of forces was increased. To make comparison a part of specimens was tested under pseudo static loading. On the basis of implemented testing the methods of calculation of formation of regular and sloping cracks, strength of regular and slant cracks as well as strength along technological joints and adjacent zones with floors are offered. The change of walls' deformation at different stages of work has been depicted through different stages of work and the values of permissible warps of wall elements are recommended.

### PERFORMANCE OF PRESCRIPTIVE CODE REQUIREMENTS: SEISMIC DESIGN PROVISIONS OF ACI 318-05 FOR COLUMNS – ID 1347

*S. Bae, University of Texas, United States*
*O. Bayrak, University of Texas, United States*

In strength-based design, as part of commonplace seismic design practice, reinforced concrete columns are designed and detailed to have sufficient lateral deformation capacity in order to ensure satisfactory behavior during strong ground motions. In this context, the effects of the amount, arrangement and spacing of confining reinforcement in plastic hinge regions have been extensively researched. As a result, several performance-based design procedures for confining reinforcement in concrete columns have been proposed, which relate required confining reinforcements to required deformation demands. In contrast, the current American building design code requirements (ACI 318-05) for the design of confining reinforcement in concrete columns are prescriptive and do not explicitly take into account deformation demands. Since these expressions are not explicitly linked to a deformation capacity, concerns have been expressed about the satisfactory seismic performance of concrete columns designed in accordance with the ACI 318-05 code. A simple method that can be used to estimate the deformation capacity of a concrete column is introduced in this paper. The validity of this simple method is evaluated using a large number of column tests collected from the literature. Using this method, the current column design practice according to the ACI 318 code is examined. It is found that columns designed using the seismic design provisions of ACI 318 display satisfactory seismic performance (drift capacity $> 2.5\%$) in most cases. It is also found that columns supporting moderate or high axial loads may not have sufficient lateral drift capacity if they have relatively large shear spans with respect to their section sizes. In light of the research results presented in this paper, the relevant provisions of ACI 318-05 are critically examined.

### EXPERIMENTAL AND ANALYTICAL STUDY OF THE SEISMIC RETROFITTING OF UNREINFORCED MASONRY – ID 1397

*D. M. Ruiz Valencia, Pontificia Universidad Javeriana, Colombia*

A high percentage of the houses in Colombia has been constructed with unreinforced masonry (URM) without technical supervision or before the implementation of the codes for earthquake design and construction. These buildings have demonstrated poor seismic behavior in earthquakes occurred over the last 100 years in Colombia generating thousands of casualities.

For the previous reasons and taking into account that people with low economic capacity build their houses with Unreinforced masonry, a research program was developed in the Javeriana University to evaluate different alternatives for the seismic retrofitting of URM. The experimental program included 20 flexural tests, three masonry walls and 70 diagonal compression tests with the proposed rehabilitation alternatives: confining reinforcement with wooden elements, reinforcement with wire steel mesh covered with cement mortar and an exterior cable system. The increment in strength and deformation capacity is evaluated and compared with other studies related with different repair techniques (FRP).

A finite element models has also been developed for the Unreinforced masonry walls with the alternatives evaluated in order to

validate the experimental results. Additionally, a three dimensional finite element model of existing houses constructed with URM was developed to study all the alternatives tested (including advanced composites, FRP) considering technical and economical aspects.

All the alternatives evaluated increases the strength and the ductility of the masonry and it is concluded that the techniques here introduced and investigated have potentiality to decrease the vulnerability of low cost housing.

### SEISMIC ANALYSIS OF EMBEDDED STEEL CORRUGATED STRUCTURES FOR TRANSPORTATION SYSTEMS – ID 1483

*V. Belyaev, Research Centre of Capital Construction, Russian Federation*

Application of steel corrugated structures (SCS) is increasing for linings of water intakes and other transportation systems. Analysis of earthquake effects on the SCS had shown that part of large-span structures had been damaged as the dynamic soil response had been underestimated in the structure design. To design adequate SCS we need to compare calculation results with the site observation data or with the results of large-scale dynamic testing. In conditions of deficiency of site observation data a specific importance is assigned to the results of experiments with SCS scale model. In Russia such tests have been conducted on the ground seismic platforms with an explosive drive. As a SCS model we use a semicircular arch with a 2.6 m span, made from metal sheet of 2.8 mm thickness with a 125×25 mm lobe produced by ARMTEC Company (Canada). After back filling with the real soil this structure is considered as a geometrical model of a semi-circular arch with 6.5 m span (scale 1:25) of thickness7 mm made of metal with the lobe measuring 164×57 mm. During the testing the seismic vibrations of ground medium and the SCS model have been simulated in vertical and horizontal directions under single-component and plane motions of the stand. The platform (ground tray) accelerations had reached 3.0 g. Such testing permits reproducing the real conditions of SCS installation, variation of soil-shell system parameters, SCS efficiency, including bolt fastenings, at sequential rise of simulated earthquake loading up to the point of destruction. Thus, for the first time we had acquired the detailed information for comparing the calculation results that correspond testing conditions and measurement results for deformations, stresses and deflections.

### SEISMIC BEHAVIOR OF RC MEMBERS OF HISTORIC BUILDINGS – ID 1496

*M. S. Marefat, University of Tehran, Iran (Islamic Republic Of)*
*K. Karbasi Arani, University of Tehran, Iran (Islamic Republic Of)*

Seismic rehabilitation of historic buildings has been a major challenge in recent years. The first step in seismic rehabilitation is evaluation of the existing capacity. For estimating damage index and investigating the seismic behavior of RC members of a real historical building, seven half-scale specimens reinforced with plain bars have been tested. The specimens consist of columns and beams and have been tested under monotonic and reversible cyclic loading. The tests indicate significant differences between the responses of specimens reinforced by plain bars relative to those reinforced by deformed bars. A regular pattern of cracking and a relatively brittle behavior was observed while a relatively large residual strength appeared after sudden drop of initial strength and stiffness. An approximate simplified analytical model based on developing dowel action of bars has been proposed to predict limit capacity of beams and columns reinforced by plain bars. In addition recommendations for seismic rehabilitation of these members have been proposed.

### A SOFTWARE FRAMEWORK FOR COLLABORATIVE PSEUDO-DYNAMIC EXPERIMENTS USING OBJECT-ORIENTED TECHNIQUE – ID 1509

*Y. S. Yang, NCREE, Taiwan*
*K. C. Tsai, NCREE, Taiwan*
*S. H. Hsieh, National Taiwan University, Taiwan*
*K. J. Wang, NCREE, Taiwan*
*S. J. Wang, NCREE, Taiwan*
*W. C. Cheng, NCREE, Taiwan*
*Y. Y. Chang, Carleton University, Canada*
*D. T. Lau, Carleton University, Canada*

The emergence of the Internet makes it feasible to connect geographically distributed laboratories through network to perform collaborative earthquake engineering experiments. More and more research efforts have been paid on developing techniques on networked collaborative experiments due to its potential to not only larger scaled or more versatile experiments, but also more resource sharing and research collaborations. However, one of the difficulties is the compatibility among various types of experimental hardware, controlling software and analysis software. This paper introduces a software framework, called ISEE++, based on object-oriented technique for networked collaborative pseudo-dynamic experiments. The framework includes Data Center, Numerical Analysis Engine, Facility Controlling Module, Data Acquisition Module, Laboratory, Camera Control Module, Video Module and Web Broadcaster written in C++ programming language. Thanks to the natural inherence of object-oriented techniques, it is easy to append sub-classes into the framework so that integrating a new experimental facility or exchange the numerical analysis engine. A networked transnational pseudo-dynamic experiment performed between Taiwan and Canada is introduced to demonstrate the feasibility of the software framework.

### EARTHQUAKE DAMAGE DETECTION IN THE FORMER IMPERIAL COUNTY SERVICES BUILDING – ID 1569

*M. Todorovska, University of Southern California, United States*
*M. Trifunac, University of Southern California, United States*

The former Imperial County Services Building represents a rare case of an instrumented building damaged by an earthquake. In this paper, it serves as a test bed to explore - on real data - a structural health monitoring method, based on detecting abrupt changes (novelties) in the recorded seismic response using expansion in a basis of bi-orthogonal wavelets. The analysis of novelties suggests that damage first occurred at about 6.4 s, proceeded between 8.2 and 9.2 s, and culminated at about 11.2 s with the collapse of the first story columns at the east side of the building. These times are consistent with large interstory drifts, and significant drops in the NS and EW system frequencies. The spatial distribution and relative magnitudes of the novelties were generally consistent with the observed damage. This method was more effective in the analysis of NS response, which was recorded by a spatially denser array (along three vertical lines, at both ends and at the center of the building), than in the analysis of the EW response (recorded only at the center of the slabs). The time delays between novelties detected in different channels, but apparently due to a common event, indicate velocity of propagation of the disturbances within the structure consistent with independent estimates from the first NS and EW system frequencies. It is concluded that this method could identify the time of occurrence and roughly the spatial distribution and degree of the major damage in this building.

### SEISMIC INSTRUMENTATION OF THE SWISS NUCLEAR POWER PLANTS – ID 1583

*C. Kuendig, GeoSIG Ltd., Switzerland*
*S. Rudaz, GeoSIG Ltd., Switzerland*
*O. Razinkov, GeoSIG Ltd., Switzerland*
*T. Biro, GeoSIG Ltd., Switzerland*

Seismic instrumentation of all of the active Nuclear Power Plants in Switzerland have been upgraded to the state of the art technology as of June 2006. The upgrades were carried out within the framework issued by the Swiss Nuclear Authority, generally based on the regulations set forth by U.S. Nuclear Regulatory Commission. Gathering the experience gained during

the upgrading of three out of four active plants, the typical approach of a distributed recording system is presented and a number of differences in technical implementations are discussed.

The purpose of the seismic instrumentation in an NPP is to provide the relevant information (recorded data, OBE and SSE alerts) so that the seismic response of the safety-significant plant features can be evaluated promptly after an earthquake. The state of the art instrumentation that have been deployed, offer to the operators additional benefits such as background noise supervision and seismic signal checks. Depending on the final sensor locations valuable information about response differences between installation sites can be determined.

The software supplied with the system is designed for fully automatic operation, which performs automatic event detection, checks whether the event can be declared as seismic and whether it meets OBE and/or SSE criteria. The software prints out the results of an entire check within a few minutes after an earthquake and displays the actual earthquake reports. Several practical aspects of the upgrade projects are discussed, including instrument mechanical and electronic design considerations, fiber optic data transmission, seismic qualification of system components, software logic and automation possibilities and service and maintenance planning. Finally, a number of planning recommendations for new seismic instrumentation and for upgrade of existing seismic instrumentation are presented.

## PERFORMANCE OF LIGHT-WEIGHT STEEL REINFORCED CONCRETE MEMBERS SUBJECTED TO ECCENTRIC LATERAL LOAD – ID 1604

*H. L. Hsu, National Central University, Taiwan*
*B. Y. Lin, National Central University, Taiwan*

Steel reinforced concrete (SRC) members, consisting of reinforced concrete and structural steel, possess high strength and significant ductility, thus are effective structural forms for earthquake resistant purposes. Although the reinforced concrete in such design can help prevent the local buckling of the encased steel and enhance the structural stiffness, the higher structural weight due to comprising concrete might limit the application of the design when seismic design efficiency is considered. In order to enhance the design efficiency, minimization of structural weight is essential. To accomplish this goal, an attempt to employ lighter concrete material, such as light weight aggregate concrete, for SRC designs is made in this study. Currently, information on the seismic behavior of SRC composite member designs using light weight aggregate concrete is still limited. In order to validate the feasibility of such designs, the member performance under earthquakes must be evaluated and guaranteed. This study is focused on the evaluation of flexural-torsional performance of light weight steel reinforced concrete members subjected to eccentric cyclic lateral load. A series of combined bending and torsional loading tests were conducted on light-weight steel reinforced concrete members with various sectional compositions to obtain their responses under earthquakes. Test results were used to define the relationship among member performance, sectional aspect ratios, and the load combinations. It was found from the comparisons that the members' flexural strength decreased when the magnitude of torsion was increased. It was also observed that the reduction in flexural strength increased when the comprising steel section's aspect ratio was increased. Finally, an empirical expression for estimating member performance under combined bending and torsional loads was proposed for design references.

## EXPERIMENTAL ANALYSIS ON A REGULAR FULL SCALE INFILLED FRAME – ID 1608

*T. Albanesi, Dis Structure Department Third University of Rome, Italy*
*S. Biondi, University of Chieti-Pescara, Italy*
*E. Candigliota, University of Chieti-Pescara, Italy*
*C. Nuti, Dis Structure Department Third University of Rome, Italy*

Monodirectional and bidirectional seismic tests on shaking table on a 3D full-scale single storey infilled r.c. frame are presented. These tests are included in "Ecoleader project" carried out at the C.E.A. of Saclay by a research team of Universities of Patras (Greece), Rome (Italy) and Chieti-Pescara (Italy). The research topic is to highlight the parameters influencing the seismic response of infilled frames and to investigate how to use these experimental data in common global analyses. The specimen represents the first floor of a two storey prototype structure also tested in Saclay and has a 4.00×4.00 square plan, 3.57 m height and four columns. Full panels are placed in two symmetric spans and two panels with window (1.00×1.20) and door (1.00×2.10) openings respectively are considered in perpendicular spans. The infilling masonry panels consist of a double wall unity: an internal hollow brick panel (8 cm thickness with horizontal holes, horizontal mortar layer and lack of vertical mortar layer) and an external brick panel (12 cm thickness with vertical holes, horizontal and vertical mortar layers). Despite of Italian traditional practice, a thin r.c. slab floor is adopted instead of a tile-lintel one, in order to guarantee additional masses correct placing for second floor influence.. Structural characteristics the one floor specimen are defined according to prototype structural hypothesis. Tests on bare frame are carried out first at low seismic intensity in order to characterise structural characteristics and to check design provisions; then tests on infilled frame are carried out at increasing seismic intensity in order to define its serviceability and ultimate limit states. Maximum peak ground acceleration in bidirectional tests are increased up to infill panels (i.e. infilling panels with openings) failure.

## NEW TRENDS IN EARTHQUAKE PROTECTION: THE SEISMIC SAFETY OF RC AND STEEL MOMENT RESISTANT FRAME STRUCTURES – ID 1620

*B. Csak, Budapest University of Technology and Economics, Hungary*
*G. Nagy, Polivent Ltd., Hungary*
*O. Kegyes-Brassai, Budapest University of Technology and Economics, Hungary*

Recent significant earthquakes (Kobe, Northridge, San Fernando, etc.) offered adverse experiences about the earthquake resistance of frame structures. Such structures designed according to the modern seismic codes were damaged seriously, a few of them were collapsed. - The most vulnerable zone of reinforced concrete structures are the joints of beams and columns. The horizontal displacements caused by the earthquake result in a cyclic alternating load on the joint. Bending, shear and normal stresses with changing sign result in the forming of cracks, finally in the crumbling of concrete, adhesion between steel reinforcement and concrete. The connections lose their energy-absorption capacities, and as a consequence all resistance capability of the entire structure. - Such degradation form is also important in case of steel frames, because of the buckling of the web and the flange. Several improvements were made in order to increase the safety of the joints without any remarkable result. The fasteners (rivets, bolts, welding) resist the stresses, but the connected elements (beams and columns) lose their resistance due to buckling. We propose a new material to use at the joint region of frame structures, the 3P resin concrete which is a ductile material. The joints are formed with plastic hinges, which offer a satisfying resistance against earthquake loads. - In the case of reinforced concrete structure the cement concrete is replaced by the 3P resin concrete at the critical zone of the plastic hinge. - In the case of steel frames the critical zone for buckling is filled up with the same material. Our promising experimental results could serve as a basis for seismic resistance of buildings with high ductility, energy absorption capacity.

## DYNAMIC TESTING WITH NEW GENERATION OF ACCELEROMETERS – ID 1627

*L. Zanaica, University of Padua, Italy*
*M. Q. Feng, University of California at Irvine, United States*
*M. Grendene, University of Padua, Italy*
*D. Kim, University of California at Irvine, United States*
*C. Modena, University of Padua, Italy*

Real-time monitoring of civil infrastructure systems such as buildings, bridges, and dams is becoming fundamental for the homeland safety and security. Sometimes conventional electromagnetic sensors are not suited for large-scale civil monitoring due to cumbersome cabling and, often, due to consistent EMI. In the course of experimental research which was carried out at the Laboratory of the Civil and Environmental Engineering Department of The Henry Samueli School of Engineering, the research was begun with the aim of investigating the real possibilities to use a new generation of sensors, with sensing mechanisms based on Moiré fringe phenomena. The first part of the tests is finalized to the physical identification of the accelerometer. A numerical algorithm, studied for the real time, efficiently eliminates the physical deficiencies of the sensor seen like an accelerometer. To confirm the real efficiency of the optical fiber sensor, it is dealt a comparison among dynamic signals gathered from this sensor with those from others two types of accelerometer for the same type of test carried out in the Cal-(IT)2 Building. The second part of the tests verifies the real possibility of application for the optical fiber accelerometer. Dynamic tests with a shaker are made on a building model. After a dynamic identification of the structure, it is damaged in order then to localize the damage thanks to algorithms which are already experimentally verified. Piezometric accelerometers are used too in order to give conclusions comparing results. This new generation of accelerometers is completely comparable to others since long time in commerce, indeed the signal is almost with no interference and its resolution is of high level. Mode shapes definition and damage localization is facilitated. These sensors are suitable very well for those applications where electromagnetic noise would disturb signals.

## EXPERIMENTAL STUDY ON SEISMIC STRENGTHENING OF SQUARE CONCRETE COLUMNS WITH LAP SPLICE DEFICIENCIES – ID 1635

*V. Zanjanizadeh, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iran (Islamic Republic Of)*

This paper describes experimental studies on seismic retrofit of reinforced concrete square columns with poor lap splices, 90 degree hooks, widely spaced transverse bars in plastic hinge regions according to ACI detailing (pre-1971) using GFRP wrapping of plastic hinge region. Three specimens were tested under the condition "as built". Three others were tested after they were retrofitted by wrapping them with a glass-fiber-reinforced plastic sheets. All specimens were tested under lateral cyclic loading with a constant axial load ratio. FRP composite wraps were used for strengthening the concrete columns in critically stressed areas near the column footing. The physical and mechanical properties of composite wraps are described. Seismic performance of retrofitted columns in term of the hysteretic response is evaluated and compared to those of the original and unretrofitted columns. The results indicate that the proposed retrofit technique is very effective. Both flexural and ductility of strengthened columns were higher than those of the original columns.

## STRUCTURAL BEHAVIORS ON THE MOMENT-RESISTING PRECAST CONCRETE BEAM-COLUMN JOINT WITH CONNECTION REINFORCING BARS – ID 1701

*K. Seung Hun, Hanbat National University, Korea, Republic Of*
*M. Jeong Ho, Hannam University, Korea, Republic Of*
*L. Yong Taeg, Hanbat National University, Korea, Republic Of*

In this study, new moment-resisting precast concrete beam-column joint is proposed for moderate seismic regions. It consists of half precast U-beam, precast column, and connection reinforcing bars. The connection reinforcing bars are penetrated the joint and lap-spliced with the bottom bars of precast U-beam. They are out of contact vertically with bottom bars. To evaluate the performance for the proposed joints, two types of specimens are tested in this study. One is for the beam tests to investigate the performance for the noncontact lapped splices. Major variables for tests are the lengths of lap(0.8lb, 1.0lb, 1.2lb, 1.4lb), the diameters of connection reinforcing bars(D19, D22, D25), and the distances between lapped bars. Test results show that these variables have much influence on strength and ductility, and deformation of specimens. FEM analysis is performed to verify the bond and failure mechanism of specimens. Analysis results show a good agreement with the test results. The other is for the cyclic tests to investigate the joint behavior subjected to reverse cyclic loading and constant axial compressive load. Three precast beam-column interior are tested. The variables examined are the diameter of connection reinforcing bars and the presence of transverse reinforcement in the joint. Structural performances of joint are evaluated on the basis of connection strength, stiffness, energy dissipation, and drift capacity. Based on the test results, the proposed precast connection is capable of matching or exceeding the performance of the monolithic connection and thereby provides the sufficient moment-resisting behavior to be applicable for moderate seismic regions.

## BEHAVIOR OF SQUARE REINFORCED CONCRETE COLUMNS RETROFITTED WITH CFRP AND AFRP – ID 1890

*S. Mehdizad Taleie, Sharif University of Technology, Iran (Islamic Republic Of)*

The majority of buildings in the regions of high seismicity in Iran do not meet seismic code requirement, and many of these buildings are vulnerable in severe earthquakes. Concerns for seismic rehabilitation of existing buildings grew considerably in the recent years, and has been accelerated since the Bam earthquake 2004. FRP retrofitting techniques is increasingly used to overcome the lack of ductility in RC buildings. This paper presents the results of an experimental research program on RC columns retrofitted by CFRP and AFRP composites. Eight half-scale square concrete columns are subjected to a combination of axial compression and cyclic shear load. Variables investigated in this program include the amount of axial compression, the type and arrangement of FRP and prestressing level of aramid strips. The results indicate the noticeable advantage of the prestressing technique used in this research

## LIGHTLY REINFORCED CONCRETE SQUAT SHEAR WALLS UNDER STATIC-CYCLIC LOADING – ID 2026

*C. Greifenhagen, Switzerland*
*P. Lestuzzi, Ecole polytechnique fédérale, Switzerland*
*M. Badoux, Switzerland*

The static-cyclic behavior of lightly reinforced squat shear walls that are not designed for earthquake actions is addressed herein. Such walls provide lateral stabilization to a significant number of existing buildings. They are often supposed to fail in brittle shear and, consequently, poor seismic performance is expected. Experimental investigations are conducted on a series of four specimens modeling the bottom part of a real shear wall in 1:3 scale. The specimens are tested as cantilevers subjected to both constant axial force and static-cyclic lateral loading. Uniformly distributed rebars provide reinforcement ratios of 0.003. It is shown that non-ductile, lightly reinforced walls can attain drifts between 0.8 and 2.1 % at nominal shear stresses of 1.4 up to 2.0 MPa. This depends on both concrete compressive strength and axial force ratio. The maximum shear capacity is governed by flexural strength while shear failure restricts the deformation capacity. Failure modes are reinforcement rupture, sliding, and concrete crushing for shear ratios of 0.30, 0.38, and 0.52, respectively. The shear ratio refers to the base shear divided by both concrete gross-section and square root of concrete compressive strength. The plastic deflection of the specimens is composed of flexure (70 %) and shear portions (30 %). Depending on the test unit, up to 70 % of the introduced energy is dissipated. Thus, it is found that lightly reinforced walls can have similar energy dissipation ratios as walls of ductile design. Principal contributor to energy dissipation is sliding in cracks. The test results fail to confirm the beneficial effect that horizontal reinforcement is widely believed to have on deformation capacity.

The observed shear strength originates partly from inherent shear strength of concrete. Since this contributor to shear strength is not included in truss models, such models underestimate significantly the shear strength of squat walls.

### AMBIENT NOISE IDENTIFICATION OF PRINCIPLE MODAL PARAMETERS OF FCE BUILDING, LJUBLJANA, SLOVENIA – ID 2071

*G. Trendafiloski, IZIIS-Skopje, Macedonia*
*Z. Milutinovic, IZIIS-Skopje, Macedonia*
*P. Zupancic, EARS, Seismological Office, Slovenia*
*B. Sket Motnikar, EARS, Seismological Office, Slovenia*
*A. Gosar, EARS, Seismological Office, Slovenia*

The microtremors HVSR method is world-wide used technique for estimation of dynamic characteristics of surface soil deposits and characterization of building dynamic characteristics. A project "Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the Macedonia, Croatia and Slovenia", performed by 3 academic institutions from the above listed countries and 2 from Italy, has recently been launched under the auspices of NATO Science for Peace Program (NATO SfP 980857). The project promotes a new integrated method and technology for "fast" seismic microzoning and seismic vulnerability assessment of buildings with wide application possibilities in particular for identification of locations with potential soil-structure resonance and thus, the increased buildings seismic risk. A joint effort of IZIIS-Skopje, EARS and Faculty of Civil Engineering (FCE), Ljubljana has been made to qualitatively and quantitatively elucidate application margins of microtremors HVSR technique for "Output-only modal identification" i.e. "ambient noise identification" of the principle building modal parameters (mode shapes, natural frequencies and damping ratios) from experimental data. The FCE building in Ljubljana was designed in 1964 and constructed in 1968. It is a reinforced concrete with mixed frames and walls 5-storey building. It is situated on alluvial deposits (sand, silt and clay). The studies of the FCE building include: (1) Ambient vibration measurements (10 vertical and 2 horizontal – storey level- profiles) performed by five ultra compact, all-in-one 3-component Tromino seismic noise acquisition instruments; (2) processing of recordings with HVSR technique; and, (3) identification of principle building modal parameters by ARTeMIS software package. The study is focused on comparison of results obtained by this study (HVSR and specialized techniques for identification of modal parameters) with published analytical studies of the FCE building including nonstructural elements.

## ES 3g: Structural Engineering - Steel
Level-1

### COMPARING OF THE IRANIAN SEISMIC STANDARD AND THE GUIDELINE FOR THE SEISMIC REHABILITATION GUIDELINE – ID 36

*A. Keyvani, Iran (Islamic Republic Of)*

Guideline for the Seismic Rehabilitation of Existing Buildings (GSREB) has been used for vulnerability assessment of existing buildings in Iran. In this study, we evaluate the efficiency of this guideline for seismic control of buildings, which have been designed under Iranian Seismic Standard (STANDARD NO.2800) requirements. In order to compare, we designed several buildings with special steel moment resisting frames under the STANDARD NO.2800 requirements. To be concluded, the vulnerability of these buildings has been controlled by GSREB. Results of the study show that the same columns in moment resisting frames of these buildings dos not satisfy life safety performance in design hazard level.

### SEISMIC BEHAVIOR OF STAGGERED TRUSS SYSTEMS – ID 164

*J. Kim, Sungkyunkwan University, Korea, Republic Of*
*J. Lee, Sungkyunkwan University, Korea, Republic Of*

In this study staggered truss systems (STS) were designed and their seismic performances were evaluated by pushover analysis. The results were compared with the seismic performance of conventional moment resisting frames and braced frames. According to the analysis results, the STS showed relatively satisfactory lateral load resisting capability compared with conventional braced frames. However, in the mid- to high-rise STS, plastic hinges formed at horizontal and vertical chords of a vierendeel panel, which subsequently leaded to brittle collapse of the structure. Based on these observations reinforcing schemes were applied and their effects on enhancing lateral load-resisting capacity were investigated

### NONLINEAR RESPONSE OF REDUCED BEAM SECTION (RBS) MOMENT CONNECTIONS WITH BOX COLUMNS – ID 246

*M. Ghaffari, Tabriz petrochemical company, Iran (Islamic Republic Of)*
*A. Behravesh, Tabriz Univ, Iran (Islamic Republic Of)*
*Y. Ghaffari, Private company, Iran (Islamic Republic Of)*

Before occurrence of the Northridge earthquake, the flexural frames with welded flange- bolted web connections were concerned by many of engineers as the most ductile and appropriate structural systems.During this earthquake and Kobe earthquake, which happened one year later, many of buildings in which flexural frame systems had been used, were deteriorated in the region of the connection of beam to column.Researches showed that the concentration of stress at just near the column was the main reason for deterioration of this type of connections, and subsequently, some methods were offered to solve the problem, one of which is reduction of beam section near the column.In this paper the nonlinear response of moment connection with a reduction in beam section has been studied using finite element method, and the designation parameters of reduced beam section, whenever the columns are chosen to be made of box sections, has been studied, and also the stress distribution just near the column have been compared for the both welded and RBS moment connections.

Keywords: nonlinear analysis; seismic behavior; steel moment frame; plastic hinges; cyclic response;

### DEVELOPMENT OF HYBRID RECTANGULAR LINKS FOR ECCENTRICALLY BRACED FRAMES – ID 330

*J. W. Berman, University at Buffalo, United States*
*M. Bruneau, University at Buffalo, United States*

This paper describes the design, testing, and finite element modeling, of a proof-of-concept eccentrically braced frame specimen utilizing a hybrid rectangular shear link. The link is self-stabilizing and does not require lateral bracing, making it suitable for use in steel bridge piers where lateral bracing can be difficult to provide (building applications are possible as well). Equations used for design are given and references for their derivations are provided. The quasi-static cyclic testing is described, and results are reported and compared with a finite element model to be used as the basis for a future parametric study. Stable and full hysteretic loops were obtained and no signs of flange, web, or lateral torsional buckling were observed. The link was subjected to 0.15 radians of rotation in the final cycle, which is almost twice the maximum rotation allowed in building codes for links with I-shaped cross-sections. Although the final failure mode was fracture of the bottom link flange, the large rotations achieved were well above what would be required in a seismic event, indicating that hybrid rectangular links without lateral bracing of the link can indeed be a viable alternative for applications in steel bridge piers in seismic regions.

### PREDICTING THE HYSTERETIC ENERGY DEMAND IN STEEL MOMENT RESISTING FRAMES BY A NEURAL NETWORK MODEL – ID 332

*B. Akbas, Gebze Institute of Technology, Turkey*
*J. Shen, Illinois Institute of Technology, United States*

Determining the hysteretic energy demand and dissipation capacity and level of damage of the structure to a predefined earthquake ground motion is a highly non-linear problem and is one of the questions involved in predicting the structure's response for low-performance levels (life safe, near collapse, collapse) in performance-based earthquake resistant design. As a result of the developments in computer and software technology, Neural Network (NN) analysis offers an alternative approach for investigation of non-linear relationships in engineering problems. The principal aim of this study is to develop and test multi-layered feedforward NNs trained with the back-propagation algorithm to model the non-linear relationship between the structural and ground motion parameters and the hysteretic energy demand in steel moment resisting frames (SMRFs). The six design parameters for the input layer were selected to evaluate the hysteretic energy demand (output data) in SMRFs. The parameters are 1) earthquake (EQ) intensity, 2) number of stories, 3) soil type, 4) fundamental period (T), 5) strength index ($\eta$), 6) EH/EI ratio. To determine these parameters; mode, NDTH, and pushover analyses were carried out on three steel buildings with 3-, 9-, and 20-stories. The data of 22 cases were used to train the NN. The testing of the NN was done by the data of 5 testing cases. The approach adapted in this study was shown to be capable of providing the best accurate estimates of hysteretic energy demand by using the six design parameters. The results are considered to be encouraging for further research of expanded data sets. By setting up some random variations in the design parameters, it is possible to estimate the hysteretic energy demand for new or existing regular SMRFs. The results were also tested through another NN application and similar results were obtained.

### EVALUATION OF THE COMBINATION RULES FOR THE EFFECT OF THE THREE ORTHOGONAL COMPONENTS OF EARTHQUAKES – ID 338

*A. Reyes-Salazar, Universidad Autónoma de Sinaloa, Mexico*
*A. Reyes-Salzar, Universidad Autónoma de Sinaloa, Mexico*
*A. López-Barraza, Universidad Autónoma de Sinaloa, Mexico*
*S. Villela-Aragón, Universidad Autónoma de Sinaloa, Mexico*
*J. I. Velázquez-Dimas, Universidad Autónoma de Sinaloa, Mexico*

The seismic elastic and inelastic responses of steel frames under the action of strong motions earthquakes are estimated. In light of the results, the accuracy of the commonly used rules to evaluate the combined effect of the components, namely, the Square Root of the Sum of the Squares (SRSS) and the 30-percent (30%) combination rules, is evaluated. The maximum seismic responses of four three-dimensional moment resisting steel frames, in terms of the total base shear and the axial loads at interior, lateral and corner columns, are estimated as realistically as possible by simultaneously applying, first the two horizontal and then the three components. After that, the abovementioned combination rules and others are evaluated. The evaluation of the rules is performed for two cases: when the effect of the vertical component is neglected and when the three components are considered. The error introduced by applying the same response spectra in both horizontal directions is also studied. The results are calculated for both, normally recorded time histories and those oriented into their principal directions. The numerical study indicates that the effect of the vertical component is as significant as that of the horizontal components and consequently should be explicitly considered. It is shown that some rules may underestimate the combined effect. Results also indicate that such underestimation is more for inelastic analysis than for elastic analysis and that applying the same response spectra in both directions can result in conservative designs in some cases. Based on the results obtained in this study, it is concluded that the design requirements for the combined effect of the components, as outlined in some code-specified seismic design procedures, need to be modified.

### EFFECT OF THE PRINCIPAL COMPONENTS OF EARTHQUAKES ON THE SEISMIC RESPONSE OF MOMENT STEEL FRAMES – ID 339

*A. Reyes-Salazar, Universidad Autónoma de Sinaloa, Mexico*
*A. López-López, Universidad Autónoma de Sinaloa, Mexico*
*A. López-Barraza, Universidad Autónoma de Sinaloa, Mexico*
*D. López-López, Instituto Tecnológico de Sonora, Mexico*

Seismic accelerations are registered according to the orientation of the instruments. Three orthogonal components of acceleration, two horizontal and one vertical, are commonly registered. The effect of the vertical component is usually smaller than those of the horizontal components and is consequently neglected. The effect of each horizontal component is evaluated independently and combined according to some empirical rules. In addition, in seismic analysis, the recorded horizontal accelerations are applied along the structural axes. It may not represent the critical condition. According to the Penzien and Watabe Model, the ground components are uncorrelated along a set of orthogonal axes denoted as principal axes which may not coincide with those of the structure. These components are denoted as principal components and could produce the critical response. Their axes are oriented such that the major principal axis is horizontal and directed toward the epicentre. In this paper, the validity of the Penzien and Watabe Model, the degree of correlation of the recorded components and the accuracy of the most used rules to estimate the combined effect, are studied. Using a time domain nonlinear finite element program developed by the authors and their associates, the maximum inelastic seismic responses of several moment resisting steel frame structures are estimated as realistically as possible by simultaneously applying the horizontal components. The frames are modeled as complex MDOF systems. Results of the study indicate that the orientation of the major horizontal component may be quite different than that of the epicenter, that the principal components represent the critical condition in most of the cases, that some combination rules may underestimates the response, and that the effect of the correlation of normally recorded components can be larger than that obtained in linear spectral analysis of single degree of freedom systems.

### IRANIAN EXISTING STEEL BUILDINGS: STATE OF THE PRACTICE – ID 379

*B. Shafei Pamsari, University of Tehran, Iran (Islamic Republic Of)*
*P. Lestuzzi, Swiss Federal Institute of Technology Lausanne, Switzerland*
*M. Motavalli, Structural Engineering Research Laboratory, EMPA, Switzerland*
*S. R. Mirghaderi, University of Tehran, Iran (Islamic Republic Of)*

Practices of construction of steel buildings in Iran can be divided into 2 main categories according to the following time intervals: before 1990, and after 1990. Roudbar-Manjil Earthquake with the magnitude of 7.7 Ms was a milestone occurred on 20 June 1990. This earthquake had about 40,000 victims and also 60,000 injured. Large amount of damage caused by that resulted seismic design of buildings became officially mandatory for all Iranian buildings which were designed after 1990. Because of crucial effects of practices of construction on seismic performance of buildings, this paper describes common practices used widely in typical Iranian steel buildings since about 40 years ago, including the buildings before and also after 1990. The majority of Iranian existing steel buildings belong to the category of pre-1990. These buildings can be seen from faraway rural areas to large cities of Iran, and have been built according to almost no seismic code. This fact means that this category of buildings will not be capable to resist earthquakes expected in related seismic codes. After 1990, the changes emerged in Iranian buildings. Wide varieties of practices were imported to national construction industry, and traditional practices were almost abandoned. It is possible to see a wide range of steel buildings that although all of them have been designed after 1990, some of them satisfy seismic design requirements completely,

and the others suffer from obvious deficiencies against probable earthquakes. Seismic defects and also retrofitting strategies in two above mentioned categories of steel buildings will be obviously different. Hence, after introducing the common practices of Iranian steel buildings, general seismic deficiencies of these existing buildings will be considered. Final part of this paper proposes different general rehabilitation strategies that may be appropriate for typical Iranian steel buildings in order to upgrade the seismic performance of them.

### EFFECTS OF CONCRETE SLAB ON THE SEISMIC PERFORMANCE OF STEEL BEAM-TO-COLUMN CONNECTIONS – ID 664

*M. Valente, Politecnico di Milano, Italy*

Beam-to-column connections with concrete slab are modeled by a fiber section model implemented in the computer code CAST3M. The numerical model is validated comparing the results of the numerical analyses with experimental tests carried out at the Politecnico di Milano. Good agreement is obtained with the experimental results. The study shows the increase in stiffness and strength of the models due to the composite action. Results emphasized the influence of the composite slab on the connection behaviour. The seismic beahviour of steel moment resisting frame with concrete slab is studied and non-linear static and dynamic analyses are performed. Data are collected to evaluate the effects of the composite slab on the performance of welded steel beam-to-column connections. The accuracy of the fiber section model to reproduce the behaviour of the connection with concrete slab is highlighted.

### MODELING OF COMPLETE STRESS-STRAIN RELATIONSHIP FOR HIGH-STRENGTH STEEL – ID 760

*T. Fukuhara, Kyushu University, Japan*
*J. Chen, Beijin General Engineering Design Institute, China*
*Y. Sun, Kyushu University, Japan*

As the increasing utilization of high-strength steel in building constructions, it is of fundamental importance to establish a rational design method to evaluate the structural properties of a building component or member made of high-strength steel. To achieve this goal, a complete stress-strain relationship for the high-strength steel is indispensable. Purpose of this paper is to propose a simple and comprehensive stress-strain model for the high-strength steel with emphasis on the steels without clear yield plateau in their stress-strain behavior. Mathematical expressions of the proposed stress-strain model are based on the famous Menegotto-Pinto function, but the proposed model has a significant advantage over the current models in that the envelop as well as the unloading and reloading paths of the stress-strain curve can be simply determined without iterative procedures. To verify the accuracy and validity of the proposed model, cyclic loading tests were also conducted on high-strength steel rebars (KSS785) with three kinds of nominal diameters. Comparison between the test results and the theoretical stress-strain curves exhibited very good agreement.

### EVALUATION OF DEFORMATION AND ENERGY ABSORPTION CAPACITY FOR STEEL CONCRETE COMPOSITE MEMBERS – ID 838

*M. Doi, Niigata University, Japan*
*D. Kato, Niigata University, Japan*
*F. Murayama, Niigata University, Japan*
*M. Fukushima, Niigata University, Japan*

Steel concrete composite structure (abbreviated SCCS here after), for example steel encased reinforced concrete (abbreviated SRC here after) structure or concrete filled steel tube (abbreviated CFT here after) structure, has been generally adopted for the construction of high-raised buildings in Japan. External columns in the lower stories of high-raised buildings are generally subjected to large range of varying axial force under earthquake ground motion. Nevertheless, most of researches on the structural performance of SCCS beam-columns have been carried out under constant axial force. The clarification of the structural performance on structural members is necessary for the performance-based design of building structures. This paper discusses the deformation capacity and the energy dissipation performance of SCCS beam-columns subjected to reverse cyclic horizontal force under varying axial force on the basis of experimental data. Reversed cyclic loading tests on SCCS beam-columns under varying axial force have been carried out. These experimental results have been compared with those under constant axial force. Deformation capacity and energy dissipation performance of SCCS beam-columns under varying axial force is generally superior to that under constant axial force. However, SRC beam-columns sometimes show superior deformation capacity under tensile axial force, and CFT beam-columns sometimes show inferior deformation capacity under tensile axial force. Both limiting value for rotation angles as the index of deformation capacity and equivalent viscous damping as the index of energy dissipation performance of SCCS beam-columns under varying axial force are able to be estimated by evaluation method modified that under constant axial force.

### EVALUATION OF CUMULATIVE DAMAGE ON HYSTERESIS STEEL DAMPER – ID 913

*S. Atsushi, Nagoya Institute of Technology, Japan*
*O. Tetsuro, Nagoya Institute of Technology, Japan*
*S. Shoji, Nagoya Institute of Technology, Japan*

After the Northridge and Hogoken-Nanbu Earthquake, many passive controlled structure buildings were constructed in Japan. The principle of this design is to add some energy dissipation (damping) hardware into the structure and reduce the damage of buildings. In Japan, JSSI (Japan Society of Seismic Isolation) have published the design manual version 2 in Sep, 2005. And this manual is referring to the mechanism, design, fabrication, testing, quality control, and analytical modeling of various types of passive control devices, as well as design, construction, and analysis of passively controlled buildings. This manual is used by structure designer and it is very useful. One of the most popular passive control devise is steel damper. This damper is based on the yielding mechanism of the metal. Therefore, this kind of device is so called displacement-dependent damper. Steel damper is design to absorb the earthquake energy by its plastic deformation. Therefore, it is very important to understand the performance of steel in plastic range. Moreover, the damper will suffer hysterical behaviors. Thus, cyclic behavior, especially fatigue, must be understood. The design manual is based to control the drift angle of the structure; and do not considering the hysteresis of the energy dissipation hardware applying the plastic deformation. The damper will added to the structure by controlling its total stiffness and damping performance. As the result, as the maximum controlled angle shows the same result, it is possible to say that the hysteresis of the damper shows a different behavior by the difference of system stiffness and supplemental damping stiffness. However, there are no detail comments about this problem in the design manual. The purpose of this study is to mention the relationship of damper behavior and supplemental damping stiffness to the system. And also to mention what the structure designer must consider.

### VERIFICATION OF DISPLACEMENT-BASED ADAPTIVE PUSHOVER FOR SEISMIC ASSESSMENT OF HIGH-RISE STEEL BUILD – ID 956

*D. Pietra, ROSE school, Italy*
*R. Pinho, University of Pavia, Italy*
*S. Antoniou, SeismoSoft, Greece*

A number of recent studies raised doubts on the effectiveness of conventional pushover methods, whereby a constant single-mode incremental force vector is applied to the structure, in estimating the seismic demand/capacity of framed buildings subjected to earthquake action in particular when higher modes are involved in the structural response. The latter motivated the

recent development and introduction of the so-called Adaptive Pushover methods whereby the loading vector is updated at each analysis step, reflecting the progressive damage accumulation and resulting modification of the modal parameters, that characterise the structural response at increasing loading levels. Within such adaptive framework, the application of a displacement, as opposed to force, incremental loading vector becomes not only feasible, since the latter is updated at each step of the analysis according to the current dynamic characteristics of the structure, but also very appealing, since inline with the present drive for development and code implementation of displacement or, more generally, deformation-based design and assessment methods. Further, such innovative displacement-based pushover algorithm seems to lead to superior response predictions, with little or no additional modelling and computational effort, with respect to conventional pushover procedures. The verification of the accuracy of these innovative adaptive pushover techniques, however, has so far been restrained to the cases of reinforced concrete buildings and continuous-span bridges, with steel construction having been essentially overlooked. Therefore, the current paper aims at addressing such knowledge gap, by describing the results of a parametric study, whereby the accuracy of the Displacement-based Adaptive Pushover algorithm (DAP) in predicting the seismic response of 9 and 20-storey high steel buildings is investigated. A large set of natural records (from the SAC project) is used in the dynamic analyses that are carried out for comparison.

## A NEW HYBRID FORCE-DISPLACEMENT SEISMIC DESIGN METHOD FOR PLANE STEEL MOMENT RESISTING FRAMES – ID 1013

*T. Karavasilis, University of Patras, Greece*
*N. Bazeos, University of Patras, Greece*

A new seismic design procedure for regular steel moment resisting plane frames is presented. This is a hybrid procedure as it combines elements from both the displacement-based and the force-based methods. According to this method, the framed structure is replaced by the single degree of freedom substitute structure for which the design displacement, associated with different limit states, is established. By using the equation that relates the elastic acceleration and displacement spectra, the fundamental period is obtained in terms of the design displacement. Once the period is known, the elastic base shear can be easily obtained with the aid of the acceleration spectrum. This base shear is then reduced appropriately to produce the seismic design base shear of the frame. The proposed methodology is illustrated by means of a realistic design example which also serves to demonstrate its advantages over both the displacement-based and force-based seismic design methods.

Keywords: steel frames; performance-based seismic design; force-displacement

Corresponding Author: Asst. Professor N. Bazeos ( n.bazeos@upatras.gr)

## ABOUT THE BRACES CROSS-SECTIONS IN ECCENTRICALLY BRACED FRAMES – ID 1059

*H. Köber, Technical University of Civil Engineering, Romania*

"I" shaped cross-sections for braces are used very often in eccentrically braced frames. The webs of the "I" shaped braces can be placed normal or parallel to the plane of the frame. The advantages and disadvantages of these two alternative solutions are analyzed for different bracing configurations in eccentrically braced frames, located in seismic areas. The stiffness of the eccentrically braced frames under lateral loads, the values of bending moments and axial forces in different structural elements, the material consumption, the plastic hinge rotations and the remaining vertical floor displacements after dynamic nonlinear analyses were compared.

## DIFFERENT LONG LINK CONFIGURATIONS – ID 1071

*H. Köber, Technical University of Civil Engineering, Romania*

The paper is intended to illustrate the advantages of a new solution for eccentrically braced frames with long links. The lateral stiffness and the steel consumption of eccentrically braced frames with long links were analyzed and static non-linear analyses were performed to observe the history of the formation of plastic hinges.

## STIFFNESS OF STEEL FRAMES WITH BEAMS CONNECTED TO COLUMNS IN MINOR AXIS – ID 1150

*K. Peker, Erdemli Ltd., Turkey*
*N. Yardimci, Istanbul Technical University, Turkey*

In performance based structural earthquake design, the system performance is measured with the overall lateral deformation capacity of the structure, which also defines the system ductility.

All structural elements and connections affecting the lateral stiffness of the structure, has great importance in definition of real structural behavior.

The behavior of major axis moment connections are well defined and are used in the global analysis with the proper definitions of connection's moment rotation characteristics.

Due to lack of experimental and numerical research on minor axis moment connections, the beneficial affect of semi-rigid behavior of these connections are not counted for defining the real structural behavior for seismic performance.

They are either assumed to be fully rigid or pinned; assumptions that neither one is correct and leads to incorrect definition of system lateral stiffness.

In this study, 3 steel frames with minor axis moment connections will be used in a parametric study to see the affect of the semi-rigid behavior of the connection on frame performance, in case of incremental lateral loading.

Frames to be analyzed will mainly be chosen to demonstrate the behavior of low-rise, mid-rise and high-rise steel frames and their lateral stiffness.

A moment-rotation relation previously proposed by the authors will be used to define the connection's behavior in the analyzed frames during the study.

Using the findings of the parametric study, and comparisons of results authors will prepare comments to define the affect of minor axis beam to column connections on global frame behavior.

## SEISMIC PERFORMANCE OF KNEE-BRACED STEEL FRAMES – ID 1188

*R. L. Bonett-Díaz, Universidad de Medellín, Colombia*

The damages recorded during the last seismic catastrophes around the world show that retrofitting measure are not necessary guarantee a good seismic performance in terms of stability, economic and security. During moderate and strong earthquakes, structural elements must be stiff enough to control the drift to prevent structural damage, and must have sufficient ductility to prevent collapse caused by dramatic deformation of yield elements. Therefore, after strong earthquakes, these elements must be retrofitting or replaced, which is expensive and affect to functionality and operation of the building. In this work, a passive control system called "Disposable Knee-Bracing, DKB" is used to improve the seismic behavior of steel frame and to avoid damages on main structural elements. The DKB system controls the initial elastic stiffness of the frame and the yield and subsequent energy dissipation without suffering collapse or instability. Subsequent repair of the knee elements is simple and cost effective, and does not affect the main structural elements. Numerical results indicate that the yield capacity and the strength capacity of a steel frames can be increase and its global displacements can be decreased to the desired levels by directly adding knee-bracing system to the frame. The damage is focused on knee elements, which can be replacing after the earthquake, without affect of structural stability.

### EFFECT OF COLUMN BASE RIGIDITY ON POST-EARTHQUAKE REPAIR COST OF STEEL MOMENT-RESISTING FRAME STRUCTURES – ID 1228

*B. Stojadinovic, University of California, Berkeley, United States*
*A. Aviramtraubita, University of California, Berkeley, United States*

Bases of steel columns, designed to connect the column to the reinforced concrete foundation using a base plate and exposed anchor bolts, are important elements of steel moment-resisting frames. Today it is well understood that such column bases are neither rigid nor pinned: they are semi-rigid. Furthermore, the stiffness and strength of column bases significantly influences the response of the frame.

In this paper we present a study on how the actual semi-rigid structural characteristics of exposed steel column bases affect the estimates of repair cost for low-rise steel moment-frame buildings. We choose a prototype three-story tall office building at the UC Berkeley campus and modeled it using an array of column base models ranging from rigid to pinned. Using the PEER Center methodology for computing the probability of exceeding a repair cost we compared the seismic performance of these different frames in the same seismic hazard environment. We find that varying stiffness and strength of the column bases affects the total repair cost and the ratio of repair costs of structural and non-structural elements, as well as the ratio or repair cost of acceleration and displacement sensitive non-structural elements. We conclude that it is important to use a correct, experimentally confirmed, estimate of semi-rigid column base structural properties to accurately evaluate the seismic performance of moment-resisting frame buildings.

### ANALYTICAL SEISMIC BEHAVIOR OF CONCRETE FILLED STEEL TUBE COLUMNS – ID 1274

*T. Moradi Shaghaghi, Tabriz Islamic Azad Univesity, Iran (Islamic Republic Of)*
*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*

Due to improved composite effect and enhanced seismic behavior of concrete filled steel tube columns (CFST), there use in building industry, specially in construction of tall structures in seismically active regions is ever growing. They are easy to construct and erect, cost effective, need no forming, and with less equivalent materials, a better seismic behavior and more ductility in comparison to similar steel are achieved.

In these columns, development of full load bearing capacity depends on; bond strength between steel and concrete, local buckling of steel encasing, ratio of side dimension of the column to steel thickness, D/t, length to dimension ratio, L/D and finally the shape of column.

In order to study the effect of above mentioned parameters, three sets of columns with different shapes were subjected to finite element analysis by considering and varying each parameter separately under pure uniaxial load history. For comparison purposes, 12 specimens of similar columns were subjected to analysis by considering axial and increasing lateral load regime. Analysis was performed using ANSYS while analytical models were constructed and tested in similar manners in laboratory.

This paper is to present the results obtained during analytical modeling and investigations. Due to the fact that not all experimental results are complied, comparisons between analytical and experimental work will be presented in future. However, presented analytical performance and seismic behavior of CFST columns in this study by varying parameters show clearly the cut off recommendations for design of such columns. Suggestion for design consideration will also be provided in this paper.

### STRENGTHENING OF BRACED STEEL BUILDINGS – ID 1343

*P. Rafieian, Mazandaran University of Sciences and Techniques, Iran (Islamic Republic Of)*
*G. Ghodrati Amiri, Iran University of Science and Technology, Iran (Islamic Republic Of)*

The topic of this research is about strengthening of braced steel frames that designed by Iranian earthquake code(second edition) by the "seismic retrofitting provisions for existing buildings" on the basis of inherent upgrading target for thems. In these regards,at first,appropriate plans with 2,4,5,7 and 10 stories are chosen and designed by Iranian earthquake code. At next their critical frames analysed by ETABS software and controlled according to the"seismic retrofitting provisions" under base upgrading level by two methods:nonlinear static analysis and dynamic time history analysis. Members that were rejected,replaced with stronger sections and weights increment of improved structures were calculated. Finally concerning about buildings that designed by Iranian earthquake code concluded that(except 2 story building in nonlinear static upgrading method) these buildings(such as 2 story building in dynamic time history upgrading method) between 11 to 31 percent of their members are rejected and must be strengthened under base upgrading level.

### THE NEW DETAILS OF RIGID CONNECTION – ID 1344

*R. Mirghaderi, University of Tehran, Iran (Islamic Republic Of)*
*M. Dehghani Renani, University of Tehran, Iran (Islamic Republic Of)*

This paper presents new details of rigid connection. In the usual manners one beam is placed between two columns and columns cut the beam. In this system two beams pass next to column and the beams are not cut by column. Therefore there are continuous beams. This Detail connects these beams two column in properly manner.In this research, a specimen of the connection has been built in real scale and has been subjected to the cyclic loading to the lateral load applied to the structure. Along with experimental studies, connection behavior has been studied by nonlinear finite element approach. The experiment result and finite element approach that have compatibility show that bending resistance of this connection is more than bending resistance of beams. This provides the probability of plastic hinge forming in the beams and as a result the structure has ductility and safe behavior and has high capability for energy dissipation.

### USE OF CORRUGATED WEB ZONES IN SMRF BEAMS AS A TYPE OF RBS MOMENT CONNECTIONS – ID 1400

*R. Mirghaderi, University of Tehran, Iran (Islamic Republic Of)*
*S. Sobhan, University of Tehran, Iran (Islamic Republic Of)*
*S. Torabian, University of Tehran, Iran (Islamic Republic Of)*

After 1994 Northridge earthquake, extensive studies were conducted to improve performance of SMRF. Two types of SMRF connections modifications are presented to reduce the demand of plastic hing moments on the beam to column connection. These are strengthening methods and weakening methods. A common weakening method is using the prequalified RBS moment connections as described in FEMA350-353. In conventional RBS moment connections, cutting the beam flanges may induce tremendous stress concentration and may impose premature brittle failures. In this paper a new method for weakening of beam section is presented and it seems to have particular advantages. It achieves by using corrugated plates instead of flat plate in beam web in a limited zone adjacent to column face. Due to the accordion effect of corrugated web, moment contribution of beam web to total plastic hinge moment is negligible and the ultimate expected plastic hinge moment of beam section may be calculated based on the flange yielding only. As corrugated plates have adequate shear capacity the plastic hinge shear resistance can be provided without any problem. The most application of this method can be in steel plated girder and column-tree construction. Decoupling of flexural and shear stresses in flanges and web would remove stress concentration and decrease ductility demand on beam to column connections under cyclic loading. These attributes enhance the low cyclic

fatigue life of this moment frame connection. For investigating the seismic performance of this new type of RBS moment connection, some parametric 3D-finite element analyses have been executed. The analyses results have been shown that the corrugated web will improve the plastic hinge stability and accommodate large deformation capacity at the plastic hinge location. The parametric studies on beam depth show that effectiveness of this method is in deep beams with respected to shallow or wide flange beams.

### CONSIDERING THE SEISMIC RESPONSE OF CONCENTRICALLY BRACED STEEL BUILDINGS – ID 1421

*P. Rafieian, mazandaran university of sciences and techniques, Iran (Islamic Republic Of)*

Spectral linear dynamic and nonlinear static analysis were performed on buildings that designed by Iranian earthquake code (second edition) to determine the influence of brace slenderness and nonlinear behavior of concentrically braced steel buildings. The brace slenderness was varied by modifying the earthquake factor ( c ) for different seismic regions in Iran. Buildings having similar sizes in plan and 2,4,5,7 and 10 stories were examined. In addition , the response of the structures was studied for four different cities.Tehran,Mashhad , Isfahan and Abadan. The spectral dynamic analysis results indicate that the story drift generally reduces as the braces slenderness is increased. The nonlinear static analysis also shows that energy dissipation decreases as the building heights increased.

### NON-LINEAR PUSH-OVER ANALYSIS OF MULTI-STORY STEEL STRUCTURES SUBJECTED TO EXTREME GROUND MOTIONS – ID 1430

*S. Elkholy, Fayoum University, Egypt*
*U. Morsy, Fayoum University, Egypt*

The 1994 Northridge earthquake caused serious damage to modern steel structures. One year later, in the Kobe earthquake (1995), nearly one thousand steel buildings were damaged. From those events it can be concluded that modern steel-frame buildings, specially constructed to sway rather than fracture during and earthquake, are more vulnerable to collapse than had ever been considered. To reduce such damage, it is important to understand its main mechanism. To obtain full knowledge of the total behavior of steel structures under severe ground motions, it is essential to simulate the collapsing process and the trace of yielding and deformation at each structural member. The reliable numerical models are highly required as a cost effective method of obtaining a comprehensive knowledge of the main parameters that affect response of structures under severe earthquakes.

This paper focuses on using the non-linear push-over analysis method to evaluate the available ductility of several multi-story steel frame buildings and to understand the failure mechanism due to severe earthquake ground motions. The Improved Applied Element Method (IAEM) is used in the modeling of the studied multi-story steel structures. The development of this technique for analyzing the entire behavior of large-scale steel structures up to total collapse is briefly discussed. The main features of the method are illustrated. A constitutive model for structural steel is adapted to account for elastic–plastic behavior under different hazardous loading conditions and the push-over analysis procedure is applied for several examples of planar steel frames. The presented study implies the use of different modes for each building to satisfy the objectives. The results show high capability of the used method on simulating the observed damage of multi-story steel structures due to recent earthquakes.

### EXPERIMENTAL VALIDATIONS OF FRICTION DAMPED POST-TENSIONED SELF-CENTERING STEEL MOMENT RESISTING FRAMES – ID 1442

*C. Christopoulos, University of Toronto, Canada*
*H. J. Kim, University of Toronto, Canada*

New connections for steel moment resisting frames that incorporate post-tensioning elements to provide a self-centering response along with energy dissipating mechanisms to dissipate energy have been proposed and experimentally validated. These investigations have confirmed that post-tensioned connections are capable of developing similar stiffness and strength characteristics to welded connections, undergoing large deformations with good energy dissipation characteristics, but without introducing inelastic deformations in the beam or columns and without residual drifts.

In this paper, a new post tensioned steel connection for moment-resisting frames with a friction dissipative mechanism is proposed and experimentally validated. The new dissipative mechanism consists of steel plates welded to the columns and bolted to other steel plates that are welded to the beam with a friction interface in between. The friction interface consists of new Non-Asbestos Organic (NAO) break lining pads that have been developed ion the automotive industry as replacements to asbestos based pads. A series of dynamic experimental validations on three different friction surfaces and for different normal stresses applied with high strength bolts are presented. The materials display a very stable hysteretic response with little change in strength. It was also observed that following a dynamic loading protocol, de-stressing and re-stressing the bolts resulted in full recovery of the strength of the interface and that it was capable of undergoing a second dynamic testing protocol with similar stable hysteretic response.

Full-scale interior and exterior connections were then built and tested under quasi-static loading. The specimens displayed the expected self- centering hysteretic response with good stiffness, strength and ductility properties while returning to their initial position after the loading. Emphasis was also given to ultimate response, for large drift values expected under extreme loading conditions. The system was designed to form plastic hinges to protect the post-tensioning elements from excessive stressing.

### A DAMAGE ACCUMULATION CONSTITUTIVE LAW FOR SEISMIC ANALYSIS OF STEEL FRAMES – ID 1457

*A. Zambrano, Dept. of Civil Engineering, 2nd Univ. of Naples, Italy*
*M. G. Mulas, Dept. of Struct. Engng., Politecnico di Milano, Italy*

During seismic excitation, the inelastic behavior of steel I-beams is highly influenced by local buckling and low-cycle fatigue phenomena, producing a reduction in both stiffness and strength of the structural elements. In this work, on the basis of a large data-base of experimental tests on cantilever beams subjected to cyclic loading, a constitutive relation in terms of global coordinates (force-displacement F, v at top) is derived, capable to describe the reduction in stiffness and strength in terms of damage accumulation. As previously proposed in the literature, Miner's rule is extended to the case of low-cycle fatigue and a model of linear accumulation of damage is adopted. A failure prediction function is derived, in terms of S-N curves, from the results of experimental tests. Here S is chosen as the peak-to-peak amplitude of top displacement; N corresponds to a conventional point of failure, determined from the results of the experimental tests. A damage index ID is then proposed, following the Miners rule, associated to a cycle-counting rule in the case of complex load history. The constitutive relation proposed has a bilinear elastic-plastic skeleton curve; unloading is elastic and reloading takes place with a reduced stiffness. A degradation in the stiffness of both the strain-hardening and reloading branches takes place during the loading process, as a function of the proposed damage index. Similarly, strength degradation is modeled as a reduction in the force value for which the plastic branch is entered. The calibration of the parameters of the constitutive relation is performed to achieve a satisfactory fitting of experimental data, for several types of I-sections. Finally, the force-displacement constitutive relation is transformed into a moment–rotation law for the plastic hinge at the base of the cantilever beam, thus allowing for his adoption within a lumped-plasticity beam element.

### STEEL PLATE SHEAR WALL ,INTRODUCTION TO SEISMIC BEHAVIOR AND DESIGN – ID 1529

*M. Hooshmandzadeh, Islamic Azad University of Shushtar Branch, Iran (Islamic Republic Of)*

This paper is intended to provide: (a) a summary of the past experimental research on steel plate shear walls with emphasis on research done in North America; (b) a brief summary of state of practice in using steel plate shear walls in highly seismic areas and; (c) a summary of a justinitiated research program at UC-Berkeley to study cyclic behavior of steel plate shear walls and to develop seismic design recommendations. .

### COMPARISON OF DAMAGE INDEXES IN THREE STEEL STRUCTURES – ID 1542

*M. Tehranizadeh, Amirkabir University, Iran (Islamic Republic Of)*
*A. Khajeh Samani, Amirkabir University, Iran (Islamic Republic Of)*

Here in, different kind of damage indices are compared. The importance of this evaluation is due to existent structures which are not built appropriately to resist against earthquakes and need to be retrofitted. Different damage indices considering material behavior and structure behavior are proposed. These indices can be divided into two types, local damage index and global damage index. Local damage indices are used to show damage in elements and Global damage indices show damage in whole structure. Three steel frame structures with different heights are analyzed by a nonlinear time history procedure and local damage indices for three earthquakes. It shows that severe damage in these structures will occur in upper levels in high-rise structures and for structures which are designed based on force based design, damage distribution across story levels is not equal. Combined damage indices are generally more accepted. In many damage indices, some coefficients are used and they must be tuned for different structures. Another major disadvantage in some local damage indices is lack of calibration for varying degrees of damage. Values derived from different damage indices are extremely sensitive to behavior model purported for material. Global damage indices computed by weighted average are as reliable as local damage indices used to calculate local damage. Global damage indices based on modal parameters depend on their hypotheses and the modal parameters that are used in their calculation.

### THE BEHAVIOR OF STEEL BUILT-UP DOUBLE-I COLUMN WITH SIDE PLATE MOMENT CONNECTION UNDER CYCLIC LOADING – ID 1612

*A. Deylami, Amirkabir University, Iran (Islamic Republic Of)*
*M. R. Shiravand, Amirkabir University, Iran (Islamic Republic Of)*

Numerous welded steel moment-resisting connections failed during the Northridge earthquake. Although a variety of different types of fractures were observed, but the brittle fracture of T-joint groove weld of the beam flange to the column, due to triaxial stress concentration were the most common types, The Sideplate connection contains a pair of full-depth side plates connecting the beam to the column. The beam never touches the column. The physical separation between beam and column eliminates the peaked triaxial stress concentration. In order to improvement the inelastic behavior under earthquake, we have studied possibility of using side plates to modify the traditional connection geometry of I-shaped beam to built-up column. This new geometry for beam to built-up column connection eliminates recognized brittle behavior and all uncertainties that are intrinsic with the use of a T-joint complete penetration groove weld to connect beam flanges directly to built-up column. Using side plates eliminates complex high order magnitude triaxial strains at the beam-to-column interface and inherently weak panel zone participation of the built-up column web. For this purpose, a series of non-linear three dimensional finite element models are developed to study the behavior of using side plate connection geometry for beam to built-up column under monotonic and cyclic loadings. The results of analytical models indicate that this new connection geometry has sufficient stiffness, strength and ductility to classify as a rigid and ductile connection.

### THE NON-LINEAR BEHAVIOR OF SIDE PLATE MOMENT CONNECTIONS – ID 1613

*A. Deylami, Amirkabir University, Iran (Islamic Republic Of)*
*M. R. Shiravand, Amirkabir University, Iran (Islamic Republic Of)*

Numerous welded steel moment resisting connections failed during the 1994 Northridge earthquake and 1995 Kobe earthquake. Although a variety of different types of fractures were observed, the brittle fractures of the T-joint groove weld of the beam flange to the column were the most common types. One of the new connections born for the design and construction of ductile steel structures after the Northridge earthquake is known as SidePlate connection. The technical reaches of this new connection are keenly suited for the high ductile performance expectations of structural building systems in the seismic zones. The Sideplate connection contains a pair of full-depth side plates connecting the beam to the column, so the beam never touches the column. The physical separation between beam and column eliminates recognized brittle behavior and all uncertainties that are intrinsic with the using of T-joint complete penetration groove welds to connect beam flanges directly to the column. In addition, using side plates eliminates complex high order magnitude triaxial strains at the beam-to-column interface and inherently weak panel zone participation of the column web. In this research, a Number of non-linear three dimensional finite element models are developed to study the behavior of the side plate connection under monotonic and cyclic loadings. The results of numerical models indicate that this new connection geometry has sufficient stiffness, strength and ductility that can be classified as a special moment frame (SMF) Connection suitable for seismic zones.

### IRANIAN EXISTING STEEL BUILDINGS: STATE OF THE PRACTICE; PART 1: NON-ENGINEERED PRACTICES – ID 1779

*B. Shafei Pamsari, University of Tehran, Iran (Islamic Republic Of)*
*P. Lestuzzi, Swiss Federal Institute of Technology Lausanne, Switzerland*
*M. Motavalli, Structural Engineering Research Laboratory, EMPA, Switzerland*
*S. R. Mirghaderi, University of Tehran, Iran (Islamic Republic Of)*

Iranian existing steel buildings can be divided into two main categories. The first category includes a wide range of steel buildings a large number of which were built before 1990, and their construction was based on neither seismic nor non-seismic codes. These buildings have been designed mainly according to the experiences of traditional architects, and their patterns of construction can be named as Iranian "Non-Engineered Practices". In contrast to the first category, there are Iranian steel buildings which have been constructed according to the "Engineered Practices", and the contemporary codes have been considered in their design and configuration. The common characteristic of buildings of the second category is that although these buildings have a reliable gravity load system, there is serious doubt about their ability to resist earthquake loads. These two types of practices have had crucial effects on the current seismic performance of Iranian steel buildings. Based on the experiences of past earthquakes, it has been confirmed that these practices which are based on almost no seismic code or document can not satisfy seismic requirements of steel buildings properly, and therefore finding their weak points is essential. In the present paper, after introducing the common "Non-Engineered Practices" of Iranian steel buildings, their general seismic deficiencies are considered. The final part of this paper proposes different general rehabilitation strategies that may be appropriate for typical Iranian steel buildings. It should be mentioned that the "Engineered Practices" of construction have been described in the Part 2.

### IRANIAN EXISTING STEEL BUILDINGS: STATE OF THE PRACTICE; PART 2: ENGINEERED PRACTICES – ID 1780

*B. Shafei Pamsari, University of Tehran, Iran (Islamic Republic Of)*
*P. Lestuzzi, Swiss Federal Institute of Technology Lausanne, Switzerland*
*M. Motavalli, Structural Engineering Research Laboratory, EMPA, Switzerland*
*S. R. Mirghaderi, University of Tehran, Iran (Islamic Republic Of)*

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### DEVELOPMENT OF A SIMPLE PLASTIC HYSTERETIC DAMPER – ID 1835

*A. Neulichedl, Ingenieurbüro Neulichedl & Partner, Italy*

Steel is a very ductile material and is thus in principle very suitable for structures exposed to earthquakes. Concentrically braced frames represent a very simple, efficient and thus very often used kind of bracing. Because of their slender and aesthetically pleasing shape, X-braced frames utilising tension-only braces are of particular interest. For cyclic loading, as in the case of earthquake actions, concentrically braced frames are in general not so efficient, they show a low capacity of energy dissipation. The diagonal tension rods represent in these systems the only effective dissipative element. The diagonal compression rods fail to early in most cases (buckling), which leads to contractions of the hysteretic curve. In order to prevent a too early collapse of the compression diagonals, the standards restrict the admissible slenderness ratios. X-braced frames utilising tension rods or cables, commonly used nowadays for aesthetic reasons, are not suitable in their conventional design for bracings against earthquake actions. In this contribution is reported on the development of a simple, plastic hysteretic damper, which is incorporated in a concentrically braced frame. Prestressed diagonals made of round rods or cables are used together with a plastic damping element situated in the cross point. This damping element is equivalent to a small closed steel frame with a geometry matched with the diagonal bracings. As the calculation results show, it is possible to obtain a very efficient and pronounced hysteretic behaviour. Furthermore, the calculation shows that with these systems large ductilities in the displacement can be achieved also for more cycles, and thus behaviour factors of $q > 3$ can be obtained easily. The presented bracing system is characterised by its simplicity, economic efficiency, aesthetics and excellent properties of energy dissipation. The system is also very suitable for the subsequent installation in existing structures.

### STUDYING THE ENERGY DISSIPATION IN EBFS SUBJECTED TO EARTHQUAKE BY USING NONLINEAR DYNAMIC ANALYSES – ID 2075

*M. Hosseini, IAU, Iran (Islamic Republic Of)*
*M. Esmaeili, IAU, Iran (Islamic Republic Of)*

Most of the existing seismic design codes suggest using a “response modification factor” in calculation of the equivalent earthquake load to account for the energy dissipation of the structure subjected to severe earthquakes. This factor appears in the calculation of the building total seismic shear force rather than lateral load distribution calculations. This implicitly means that the code assumes the plastic behavior or energy dissipation of the system in its various stories is almost the same. To find out how far is the actual distribution of plastic hinges from the code assumption, some sets of steel buildings with eccentrically braced frames (EBFs), as a common type of moderately high rise buildings, have been studied by nonlinear time history analyses (NLTHA). The buildings have up to 15 stories and up to 3 bays, and have been analyzed by several real accelerograms. The formation trend of the plastic hinges in various elements of steel frames and the final distribution of plastic hinges over the structure body as well as the amount of energy dissipation in various hinges have been studied to compared with the lateral load pattern of the code, which show great differences in all cases. Then, buildings have been redesigned by the average load pattern obtained in the previous stage, and the NLTHA have been repeated. This time a good agreement is observed between the actual load distribution and the average pattern used for the redesigning of buildings. By calculating the ratio of the values given by this average load pattern to those given by the suggested pattern of the code, a somehow new concept of “story-dependent response modification factor” can be defined. The results show that the aforementioned ratio is more than unity in lower and higher stories of the building and less than unity in the intermediate stories.

## ES 5: Existing Structures and Earthquake Risk Reduction

Level-1

### FRAGILITY ANALYSIS OF MID-RISE RC FRAME BUILDINGS – ID 42

*M. S. Kircil, Yildiz Technical University, Turkey*
*Z. Polat, Yildiz Technical University, Turkey*

Behavior of reinforced concrete structures under the effect of ground motions has always been a subject of investigation, especially in seismic regions. Meanwhile, the damage to the building from recent earthquakes has emphasized the requirement for the risk assessment of existing building stock to estimate the potential damage for the future earthquakes. Fragility curves are useful tools which show the probability of structural damage due to earthquakes as a function of ground motion indices. In this study, fragility curves of mid-rise RC frame buildings in Istanbul were constructed based on numerical simulation. Sample buildings with different number of stories were designed according to Turkish Seismic Design Code. Incremental dynamic analyses were performed for those sample buildings using the twelve artificial ground motions to determine yielding and collapse capacity of the sample buildings. Based on those capacities, fragility curves were constructed in terms of elastic spectral acceleration for yielding and collapse damage levels with lognormal distribution assumption. Effect of number of stories on fragility parameters was investigated. It was found that fragility parameters change significantly due to number of stories of building. Finally, using constructed fragility curves and statistical methods, limit values of inter-story drift ratio were estimated for immediate occupancy and collapse prevention performance levels.

### SEISMIC VULNERABILITY OF MUSTAPHA PACHA HOSPITAL OF ALGIERS – ID 120

*M. N. Farsi, CGS, Algeria*
*M. Belazougui, CGS, Algeria*

The earthquakes of these last two decades have shown the high vulnerability of the health facilities in Algeria the majority of witch were constructed before the sixties. Many buildings constituting the more important hospitals of the more important Algeria cities (Algiers, Oran, Constantine, Annaba, etc.) are non-tied stone masonry structures. This construction system has not a satisfactory seismic resistance. The 1980 El-Asnam earthquake has totally destroyed the hospital of this city, whereas the one of Thenia city which is the more important hospital of the wilaya of Boumerdes, was partially closed because of serious damages following the May 2003 Boumerdes earthquake. The vulnerability study (1996-1998) of strategic buildings of Algiers city has concluded that the majority of the buildings of Mustapha Pacha hospital complex have a very low seismic resistance. This paper presents a vulnerability analysis of one representative building of Mustapha Pacha hospital. According to the analysis results, recommendations are proposed for this hospital complex which is of strategic importance for Algiers city.

## ASSESSMENT OF THE DIFFERENCE TYPES OF CITIES IN THE SEISMIC PRONE AREAS OF UZBEKISTAN – ID 159

*N. Mavlyanova, Seismology, Uzbekistan*
*O. Zakirov, Institute of Business and Law, Bournemouth Univers, UK*

Uzbekistan is located in the middle of the Central Asia within a zone of the high seismicity. Approximately 55 % of territory of the Republic based in the zone of expected seismic intensity VII (by MSK-scale) and higher. In these seismically dangerous areas located more than 330 cities. The construction of cities in Uzbekistan has the special features connected with its ancient history and modern development. For the assessment of seismic risk of the cities in Uzbekistan can be divided into 4 basic types: The first group concerning ancient cities (some of them have more than 2000 years history) which were formed in the place of old and big settlements and are now considerably developed such industrial centers. The buildings of these cities were formed during several centuries and characterized by complexity and variety of types of dwelling such as ancient structures and as modern buildings. Cities from the second group are the new cities formed in the last 50 years, as the centers with the advanced industries. The most of buildings in these areas are multi-storey houses. The third group includes ancient and new small cities which are characterized by a low level of industrial development and prevalence of branches of agriculture. Most of the buildings are one-storey individual. The basic part of residential buildings in republic was constructed by using local clay materials without anti seismic design. The capital of Uzbekistan city of Tashkent has a special position. After strong earthquake in 1966 Tashkent was significantly destroyed and then was built to the new and modern city. Present time there are an intensive change of engineering - geological and hydro-geological conditions in the cities. The number of vulnerability buildings is significantly increased and therefore there is an increase in the seismic risk for people living in these buildings.

## SEISMIC PERFORMANCE OF RETROFITTED SCHOOL BUILDINGS – ID 167

*Y. K. Yeh, NCREE, Taiwan*
*L. L. Chung, NCREE, Taiwan*
*T. C. Chiou, NCREE, Taiwan*
*T. K. Chow, NCREE, Taiwan*

A significant earthquake, 921-Chichi Earthquake, occurred in 1999. It caused a serious disaster in the central area of Taiwan, especially for school buildings. 921-Chichi Earthquake caused nearly half of the school buildings in the central area of Taiwan to collapse or damage seriously. 656 primary and secondary school buildings were damaged in that earthquake. Lack of seismic performance is a common problem for the existing buildings in primary and secondary schools in Taiwan. Serious casualties and losses may be resulted from the collapse of school buildings under strong earthquakes. Therefore, the retrofit of these school buildings is the most important issue in Taiwan. This paper reports that full-scale two-story three-bay school building specimens un-retrofitted or retrofitted with RC jacketing, steel jacketing, or wing walls were tested under a constant axial load and a cyclic reversed horizontal load to investigate their seismic behavior, including flexural ductility, dissipated energy, and shear capacity. OpenSees is also used to predict the moment-curvature relationship of sections and the lateral load-displacement relationship of buildings. Based on the test results, the seismic behavior of four full-scale specimens is presented. The test results are also compared to the analysis results of OpenSees. The brick wall elements and retrofitting elements can be simulated with suitable numerical models. It was found that the seismic performance of retrofitted specimens was greatly improved compared to the un-retrofitted specimen, and OpenSees could predict the lateral load-displacement relationship of such specimens with reasonable accuracy.

## STUDY OF EARTHQUAKE RESPONSE CHARACTERISTICS OF NON-ENGINEERED EXISTING HOUSINGS IN ASIA – ID 181

*S. Suzuki, Kansai Univ., Japan*
*S. Tanaka, Fuji-Tokoha Univ., Japan*
*N. Maki, Kyoto Univ., Japan*
*K. Horie, Earthquake Disaster Mitigation Research Center, Japan*
*H. Hayashi, Kyoto Univ., Japan*

A lot of one to two and three storey non-engineered house structures with RC frame masonry walls have serious problems, in which the corresponding building standard laws are not considered to the structures. This type of housing has been continuously built and is still making all over Asia from the east to the west. One of the big problems is that they must collapse or suffer from significant damage subjected to future destructive earthquakes.. This leads to human life and social losses. We have selected the two story housing built in Philippines, as typical examples. We will clarify their dynamic characteristics based on the statistic ones, strongly related to the seismic design and earthquake disaster. First, the fundamental natural frequency/period and damping ratio properties of the standard housing are obtained referring to the microtremor observation and on the artificial force-vibration tests results, respectively. Next, some valuable restoring force models are assumed based on the uni-axial static lateral force tests and they are introduced into the housing models for the earthquake response analysis using recorded ground motions. Lastly, the earthquake response analytical results are compared and examined from the viewpoint of earthquake damage and disaster, of which responses are the maximum displacement and the cumulative plastic deformation. The results conclude that the introduction of stable hysteretic restoring-force types to the housing is recommended and upgrading is required, strongly.

## DERIVATION OF VULNERABILITY FUNCTIONS BASED ON OBSERVATIONAL DATA FOR IRAN – ID 207

*G. Ghodrati Amiri, Iran University of Science & Technology, Iran (Islamic Republic Of)*
*M. Jalalian, Iran University of Science & Technology, Iran (Islamic Republic Of)*

Iran is located on one of the most seismic areas of the world. It is situated over the Himalayan-Alpied seismic belt and is one of those countries which have lost many human lives due to the occurrence of earthquakes. Therefore research work related to seismic risk assessment is very important in this country.

In this paper, existing vulnerability relationships for structures are reviewed with a view to their application to an Iranian seismic risk assessment scenario. Then based on this study and a data bank of post-earthquake damage distributions observed in earthquake events in Iran, new empirical fragility curves for different building groups are derived.

### THE REGION DIFFERENCE ANALYSIS OF CONSTRUCTION DESTROY RATE IN EARTHQUAKE DISASTER ESTIMATION – ID 219

*L. Jiang, 1China Earthquake Networks Center, China*

In the different region of China mainland, sorts of constructions have diverse architecture and different earthquake resistance. In order to quantify the influence to earthquake loss estimation caused by the difference, 66 disastrous earthquake cases are chosen to do statistical analysis, to definite the construction destroy coefficient in earthquake loss rapid estimation system. The result shows that there is great region proneness in the construction earthquake resistance in mainland. In the west region of mainland, as far as the same kind of construction is concerned, the construction destroy rate of Nei Menggu is relative big, Sichan and Yunnan's is much small. Finally, the construction destroy rate matrix of Yunnan, Xinjiang, Gansu-Qinghai, Nei Menggu region are gained by weighted mean arithmetic, using the data from earthquake loss site investigation reports.

### STRUCTURAL MEASURES FOR SEISMIC RISK REDUCTION IN MULTISTORY BUILDINGS – ID 221

*P. Satish, Jabalpur Engineering College Jabalpur, India*
*P. Dharmendra Kumar, Samarat Ashok Technological Institute, India*

Rapidly increasing population in urban areas and day to day increasing cost of land, given a birth for the construction of multistoried buildings. These multistory buildings are used for various purposes like residential, institutional and commercial uses. During earthquake these multistory buildings are most suspected to seismic failure. The performance of multistory buildings in earthquake prone areas shows that the vulnerability in its design, planning and construction practices. A large number of multistory buildings in Ahmedabad, Bhuj, Gandhidham (Part of India) and other towns suffered sever damages or dramatic collapse. This shows that the changes must be required in the design, planning and construction practices of multistoried building. The objective of this paper to put forth some suggestions and improvement in present practices and necessity of their incorporation for improving the performance of multistory buildings in earthquake prone areas. In this context this paper makes an attempt to improve seismic behavior of multistory buildings. Various failures of multistory building, which would be discussed in detail in this paper are namely, soft story effect, plan asymmetry, short column effect, effect of weak column strong beam design, poor construction practices, failure due to inelastic behavior of R.C.C. member etc. In order to minimize the risks of slipping between the superstructure and substructure various new techniques like base isolation system and friction pendulum system are briefly describe in this paper. This paper also deals with the various structural measure which would be taken for earthquake resistance construction such as, provision of bracing in soft story, seismic design of flexural members, provision of adequate confinement steel in column, reinforcement in masonry wall, harmony in dimensional proportioning, various ductile detailing aspect and rigidity in connection are describe in detail.

### THE FOUNDRY – ID 263

*C. Michel, HAGENMULLER SA, France*
*V. Davidovici, DYNAMIC CONCEPT, France*

« La Fonderie » (the Foundry) _ Economical, social and legal sciences university.

The building "La Fonderie", built in 1922, housed until 1954 a mechanical construction company. This building first had a structure made of poles, perforated arches and beams, all in reinforced concrete with some brick fillings. It also includes 2 huge naves framed by more sophisticated architecture's zones. The building is 125 meters long, 54 meters width and has a height of 17 meters. In 1997, this disused building being a part of industrial monument heritage, had to be restructured to make it a university. The first step of this reconstruction consisted in analysing the building structure and its components: concrete, steel, supporting ground. All of the above have been considered acceptable and in good enough condition. However, the global structure was no longer fulfilling the current seismic security's norms. The remit made afterward thus included majors updates in this field. The accepted project had specificities that made it different from the others: instead of locally reinforcing the existing concrete elements (e.g.: with carbon fibres) its purpose is to proceed to a general "restabilization" of the building so that seismic stresses will be minimal in the old structures. By creating many load-bearing shells and new concrete floors, and linking all these new elements to the more fragile and more flexible former structure, the seismic stresses will be transferred to the newer elements. It is this construction, currently in progress and to be completed shortly, we propose to present you during this conference.

### SEISMIC EVALUATION OF EXISTING NUCLEAR POWER PLANTS, APPLICATION IN FRANCE OF THE IAEA APPROACH – ID 265

*E. Gallitre, EDF, France*
*P. Labbé, EDF, France*

THE IAEA METHOD

The main purpose of this IAEA Safety Report 28 is to provide guidance for conducting a seismic safety evaluation programme for an existing Nuclear Power Plant (NPP) in a manner consistent with internationally recognized practice. The proposed guidance relies on well known technical findings. For instance it is reminded that a safe anti-seismic design relies more on capacities in accommodating large strains than in balancing large forces as they can be estimated on the basis of the classical engineering approach (elastic behaviour assumption and a static equivalent approach). The IAEA Safety Report recommends that criteria for seismic capacity assessment be more conservative than those accepted in conventional building industry, but more liberal than for an NPP design. For this purpose inelastic energy absorption factors are introduced as a practical inclusive method that takes into account the structural ductile capacity. In this regards, the IAEA Safety Report insists on the fact that an actual ductile capacity must be available.

SEISMIC RE-EVALATION OF FRENCH NPPs

The IAEA approach has been applied to the seismic re-evaluation of two French NPPs, Fessenheim and Bugey. The paper presents the case of Fessenheim. The following items were investigated: torsion effects, irregularities that may weaken the structure, out of plan effects for soft floors, foundations fragilities, connections between structural elements, undesirable rigidity effects of non structural elements. According to the IAEA method, ductile capacity of structures has been documented trough a review of reinforcement details of the concrete structures, ductile capacity of the steel frames junctions, weld basic properties, and in general of every crucial item relating to ductile capacity. Finally, implementation of the IAEA method proved to be efficient and resulted in a set of upgrading actions that improved significantly the seismic ruggedness of the plant structures.

### FRAGILITY-BASED EVALUATION OF THE SEISMIC RETROFIT STRATEGY FOR RC BUILDINGS IN TURKEY – ID 294

*M. A. Erberik, Middle East Technical University, Turkey*
*M. S. Gunay, Middle East Technical University, Turkey*

In this study, fragility functions are obtained for the unretrofitted and retrofitted states of a four story reinforced concrete frame building located in the town of Dinar in Turkey, and a seismic hazard analysis is conducted to determine the level of the seismic risk that the building is subjected to. The case study building under consideration was moderately damaged in 1995 Dinar earthquake and rehabilitated by adding shearwalls to the existing frame in order to enhance the seismic resistance, which is the main rehabilitation technique applied after 1995 Dinar and 1998 Ceyhan earthquakes.

For the construction of fragility curves, nonlinear time history analyses are conducted by considering the uncertainty in the ground motion and structural variability. Pushover analysis is employed for the determination of limit states and limit states are based on member-level deformation limits and performances as well as the global behaviour of the structure. Based on the resulting fragility curves generated for pre- and post-retrofit stages, the impact of the selected retrofit technique can be assessed. In addition, the observed damage state of the unretrofitted building after Dinar earthquake is compared with the result obtained according to the combined analysis of fragility and seismic hazard. In the final stage, the level of seismic risk for the retrofitted building is evaluated.

### AN EVALUATION OF SEISMIC CAPACITY OF 15-STORY BUILDING SUBJECTED TO VERTICAL DEFORMATION – ID 297

*R. Techasiriwan, EGAT Plc., Thailand*
*W. Fhagatong, EGAT Plc., Thailand*

This paper presents a seismic performance evaluation of 15-story building which is subjected to vertical deformation at the level expected for Bangkok area. This post-tensioned flat slab with reinforced concrete structure was originally not designed for seismic forces and was later strengthened according to the differential settlement. To evaluate the seismic capacity of this building, pushover analysis is carried out. In this method, a three-dimensional mathematical model with an effective beam width is created to simulate the actual nonlinear response of the building to seismic forces. The analysis procedure used in this evaluation was based on those given in FEMA–356. Also, the effects of foundation, according to the settlement, are included in the analysis. The seismic capacity is then compared with seismic demand from the expected earthquake ground motions, and the seismic performance can be determined. The evaluation results indicate that the building has almost sufficient capacity to withstand the highest intensity earthquake ground motions expected in Bangkok area. However, to improve the seismic capacity of the building, a joint connection between slab and column still need to be retrofitted.

### SEISMIC VULNERABILITY FUNCTIONS FOR SWITZERLAND – ID 331

*K. Pfyl-Lang, Basler & Hofmann, Switzerland*
*P. Zwicky, Basler & Hofmann, Switzerland*
*F. Kind, Converium Ltd, Switzerland*
*A. Zbinden, Converium Ltd, Switzerland*

For the assessment of potential seismic losses insurance and reinsurance companies work with de-terministic event scenarios coupling the seismic hazard with the vulnerability of the built environment and the exposed values. Whereas, however, a lot has been done in recent times to improve the as-sessment of the seismic hazard in Switzerland, vulnerability functions are still largely based on obser-vations and expert opinions from other countries with the additional problem of applicability. The goal of this study is therefore the definition of vulnerability functions based on characteristic features of the buildings in Switzerland. Historical macroseismic observations are the best currently available sources of damage information for Switzerland and the historical catalogue is naturally expressed in intensities. Therefore, this study is based on the vulnerability descriptions of the European Macroseismic Scale (EMS). Typical con-struction types in Switzerland are defined and compared to the standard construction types of the EMS. So far, the study is limited to the most important construction types in Switzerland: Unreinforced masonry and reinforced concrete wall structures. Using a scoring system in the style of ATC-21 the differences to the vulnerabilities of the standard construction types are expressed quantitatively result-ing in a correction of the vulnerability functions of the EMS for the respective construction types.

### SEISMIC EVALUATION OF THE MAIN CONTROL BUILDINGS OF A THERMAL POWER PLANT – ID 333

*A. Rezaei Tabrizi, ERC, Iran (Islamic Republic Of)*
*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*

Seismic evaluation of power plants is an extremely vital task in Iran. Iran being a seismically active region and experience of major earthquakes in recent years has created an environment that requires special attention to all major and important structures throughout the country. In this study, the main control buildings of a 1000 mega watt thermal power plant was investigated for its vulnerability against seismic forces. Evaluation was carried out in two phases using screening techniques as well as analytical and numerical methods. Screening methods was based on recommendation provided by FEMA-310 while analytical investigations were performed by utilizing recommendations stated by FEMA-356 for both linear and nonlinear analysis. 3D modeling was considered and both response spectrum and nonlinear static pushover analysis were used in analyzing the structure. Structure was subjected to 475 and 2475 year return period earthquakes. In earthquake with 475 year return period, the effect of uplift was also considered for further detailed investigation. Results for different performance levels were then calculated and the vulnerability indexes were identified. This paper will present the procedures used, obtained results and also recommendations for dealing with this sort of important structures both in terms of modeling and dealing with the obtained analytical results in retrofit design phase.

### SEISMIC VULNERABILITY EVALUATION OF A 150M R/C STACK IN A THERMAL POWER PLANT – ID 334

*A. Rezaei Tabrizi, ERC, Iran (Islamic Republic Of)*
*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*

Seismic evaluation of power plants is an extremely vital task in Iran. Iran being a seismically active region and experience of major earthquakes in recent years has created an environment that requires special attention to all major and important structures throughout the country. In this project, a 150 meters R/C Stack in a thermal power plant in western province of Hamedan was investigated. This study of course included all different sections of the power plant, however in this paper only the seismic behavior of this tall stack will be presented. Main document used for the evaluation of this stack was ACI-307. According to the recommendation of this manual, bar elements and concentrated mass was utilized for the analysis. Also to further investigate the true behavior and compare the results by the recommendations, a finite element analysis was also performed. In finite element analysis, due to modeling capabilities, also all of the openings were considered. In this study using both methods, periods, displacements, modal participation factors, base shear and overturning moments were studied and compared. This paper is to present both of procedures used, comparisons made and results obtained. It will also provide few recommendations for modeling and possible retrofitting techniques which were considered for this project.

### RETROFITTING CONCRETE FRAMES AGAINST EARTHQUAKES – ID 336

*F. Shalouf, University of Ottawa, Canada*

Performance of reinforced concrete structures during previous earthquakes has indicated that the majority of buildings designed prior to the enhancement of modern seismic codes and those designed more recently in regions where code enforcement is difficult to achieve, have suffered seismic damage associated with non-ductile frame construction. More recent earthquakes, including the 2005 South Asia Earthquake in Pakistan have underlined once again seismic risks associated with non-ductile construction. In some cases seismic resistance of these buildings was not sufficient even under moderate levels of earthquake excitation. Because it is not economically feasible to replace seismically deficient building infrastructure with new and improved buildings, seismic retrofitting remains to be the most viable approach to seismic risk

mitigation. An appropriate retrofit methodology for non-ductile frames is to provide sufficient bracing and deformation control so that non-ductile frame elements remain essentially elastic during earthquakes; the retrofitting was done by using diagonal prestressing cables. The prestressing provides sufficient lateral bracing forces without the need for large areas of steel. The paper includes the results of analytical research that involves dynamic analyses of selected reinforced concrete frame buildings. The results indicate that, the drift can be controlled by using diagonal prestressing cables and depending on the amount of strands used and the level of initial prestressing applied

### TYPOLOGICAL FRAGILITY CURVES FROM ITALIAN EARTHQUAKE DAMAGE DATA – ID 386

*M. Rota, ROSE School, Italy*
*A. Penna, EUCENTRE, Italy*
*C. Strobbia, EUCENTRE, Italy*

Extensive damage and usability post-earthquake surveys have been carried out in Italy during the last 30 years. These data have been used to derive typological fragility curves for typical building classes. Building typologies have been selected based on vertical bearing structure, characteristics of horizontal structure, number of storeys, construction period (considering earthquake resistant design prescriptions). As a starting point, the classification proposed in the RISK-UE project has been used. However the choice of the typologies is related to the type of information provided by the survey forms. Different forms have been used after different events and, obviously, only common information can be used for the selection of buildings typologies. Moreover, each form has been converted into databases, organized in different ways. Therefore a complex "re-codification" of the available information has been necessary. Different damage scales have been converted into a unique one with 4 damage grades: no damage, slight damage, severe damage and collapse. As a measure of the earthquake severity experienced by each building, PGA has been selected and estimated for each municipality, using an attenuation law. A major problem of deriving fragility curves from empirical data is that post-earthquake surveys are often carried out only on request: hence data concerning lower damages are generally incomplete, leading to overestimation of the relative percentage of severely damaged buildings. This problem is addressed in the work and a possible solution is proposed. Fragility curves have been derived for the different building typologies, after a statistical treatment of the data. The experimental damage probability matrices have been processed in order to infer the parameters of different functional relationships relating damage probability to PGA. Nonlinear regression procedures have been implemented to obtain the curve parameters, fitting the experimental points considering the relative reliability of each point, depending on the sample size and quality.

### RESPONSE MODIFICATION FACTORS FOR CONCENTRIC STEEL-BRACED RC FRAMES – ID 396

*R. Akbari, School of Civil Engineering, University of Tehran, Iran (Islamic Republic Of)*
*M. H. Adibrad, School of Civil Engineering, University of Tehran, Iran (Islamic Republic Of)*
*S. M. Najafi, Civil Eng. Dept., Isfahan University of Technology, Iran (Islamic Republic Of)*

Steel bracing of RC frames has received some attention in recent years both as a retrofitting measure of existing RC buildings and as a shear resisting element in seismic design of new buildings. Earlier investigators focussed on the retrofitting aspect of bracing and studied external bracing of buildings as well as internal indirect bracing of individual bays of the RC frames. Lately, the direct bracing of RC frames has attracted more attention since it is less costly and can be adopted not only for retrofitting purposes but also as a viable alternative to RC shear walls at pre-construction design level. Experimental as well as analytical investigations have studied the capabilities of the direct bracing system of RC frames with encouraging results. To be able to carry out seismic design of steel-braced RC frames, some key response parameters, including ductility and behaviour factor should first be established. In this paper, response modification factor parameters for concentric (X and Chevron) steel braced RC frames of different heights and brace-frame configurations are evaluated. The parameters including ductility, ductility reduction factor and overstrength are extracted from response curves obtained from inelastic adaptive-based pushover analyses of braced-frame system. The effects of some parameters influencing the value of R factor, including the height of the frame, bracing system and different ductility demands are investigated. It is found that these parameters have a more localised effect on the R values and their influence does not warrant generalisation at this stage. However, the height of this type of lateral load-resisting system has a profound effect on the R factor, as it directly affects the ductility capacity of the dual system. Finally, based on the findings presented in the article, tentative R values are proposed for steel-braced moment-resisting RC frame dual systems for different ductility demands.

### A GENERALIZED MODEL FOR DECISION MAKING IN REHABILITATION OF STRUCTURES – ID 438

*M. Asheghan, University of Tehran, Iran (Islamic Republic Of)*
*C. Lucas, University of Tehran, Iran (Islamic Republic Of)*
*G. Sobhaninejad, University of Tehran, Iran (Islamic Republic Of)*

In this paper we tried to model uncertainties which are involved in decision making progress for rehabilitation of structures. The usual methods define a decision function based on an economic aspect of rehabilitation. (E.g. Cost of Rehabilitation / Cost of Reconstruction). Usually the probability is the only kind of uncertainty which is considered in decision progress and two other major fields of uncertainty (Possibility and Ignorance) are ignored. We use the Modified Dempster-Shafer theory to consider all three kinds of uncertainty (probability, fuzziness and ignorance) in decision making process and we show that two of them (which are usually ignored) can change the result. As an example of using this theory we used the proposed algorithm to make a decision on a real case which is evaluated based on FEMA-356.

### COST-BENEFIT ANALYSIS FOR REHABILITATION OF RC BUILDINGS IN TURKEY – ID 445

*A. Yakut, METU, Turkey*
*S. Cetinceli, METU, Turkey*

The need to rehabilitate existing buildings with poor performance continuously increases as clearly revealed by recent studies indicating a high probability of a damaging earthquake to affect the Marmara region in Turkey. With the rising cost of damages due to earthquakes, the necessity of the cost-benefit analysis for various rehabilitation strategies used in existing buildings has become a major concern for the decision makers who are in the position of making decisions on the building rehabilitation strategies. This study evaluates the performance of two different rehabilitation strategies applied to two five-story reinforced concrete buildings and assesses their cost-benefit analyses. These buildings were chosen to be representative of the typical residential buildings in Turkey. Two alternative strengthening methods, insertion of reinforced concrete shear walls and application of Carbon Fiber Reinforced Polymers (CFRP) on hallow clay tile infill walls, were used for both of the buildings. Pushover analyses were performed to evaluate seismic performance of the buildings. The Life safety criterion was chosen as the rehabilitation objective. The global and component response acceptability limits were checked and the cost-benefit analysis was performed in order to determine the most attractive rehabilitation alternative. The results and comparisons illustrated that the seismic performance and cost effectiveness of the rehabilitation alternatives are directly related to the shear wall density, evaluation criteria and the selection of the response quantity.

### PERFORMANCE-BASED RISK ASSESSMENT AND RETROFIT GUIDELINES FOR SCHOOL BUILDINGS IN CANADA – ID 462

*T. White, University of British Columbia, Canada*
*G. Taylor, TBG Seismic Consultants Ltd., Canada*
*C. Ventura, University of British Columbia, Canada*

In 2004, the Province of British Columbia, on the West Coast of Canada, announced an ambitious 10-15 year, $1.5 billion seismic retrofit program for the province's 750 at-risk schools. The purpose of this earthquake preparedness initiative is to accelerate the upgrading of school public safety in the moderate and high seismicity regions of the province. Given the magnitude of the mitigation program, the Ministry of Education and Western Economic Diversification Canada made a commitment to support the development of state-of-the-art performance-based seismic engineering technology for achieving optimum safety within a cost-effective mitigation framework, which could not be achieved based on best current practice. This paper describes one component of this technical development program, the formulation of performance-based structural assessment and retrofit design guidelines, which are currently being used by engineers to determine retrofit strategies for schools in British Columbia. The guidelines include fourteen different types of low-rise construction, covering five seismic zones and three soil types in British Columbia. The guidelines provide minimum lateral strength requirements to achieve different levels of drift. Additionally, the guidelines have procedures to allow engineers to combine different structural systems, and to account for existing materials that are typically discounted in current practice. Non-linear dynamic analysis and non-linear static analysis were used to predict the response of the prototype models, which represent the generic response of a given type of low-rise construction. Ground motions records from Loma Prieta and Northridge were scaled to match the seismic demands specified in the 2005 National Building Code of Canada, which are based on a probability of exceedance of 2% in 50-years.

## EVALUATION OF SEISMIC RETROFITTINGS METHODS FOR MASONRY JACK ARCH SLAB – ID 482

*S. A. Zahraei, Iran University of Science and Technology and BHRC, Iran (Islamic Republic Of)*
*R. Edalatmanesh, ran University of Science and Technology, Iran (Islamic Republic Of)*
*M. Zahrai, University of Tehran, Iran (Islamic Republic Of)*

Due to easy construction together with low cost of jack arch slabs, they have been widely used in many countries like Iran. Nowadays, many low-rise buildings are still constructed by this flooring system. According to statistics, failure of unstable floor slab has reported as one of the important reason for collapsing the structures in Iran deadly earthquakes, so designation and evaluation of control systems of masonry slabs in standard codes have found special significance in recent years. For this purpose, after applying and assessment of finite-element computer-based models, 3 one - story, one – span, 3D experimental specimens consisting a non-retrofitted traditional slab, a retrofitted model on the basis of FEMA 356 and finally an authors' prescribed method have been tested to evaluate the usual and innovative retrofitting methods .Floor slab stiffness changes, floor diaphragm performance and fracture mechanism for these models are investigated to disclose positive effects of retrofitting methods on seismic structural behavior. The retrofitting method according to FEMA 356 was an in plane rebar X-bracing on the floor. After adding another in-plane rebar X-bracing to earlier model , on the basis of authors' plan, remarkable improvement in almost all of the important structural parameters was perceived. In conclusion, usage of retrofitting methods for available traditional masonry jack arch slabs can be an effective and economical way for reducing the earthquake hazards.

Keywords: Jack-arch masonry slab, seismic retrofit, floor diaphragm, cyclic behavior

## SEISMIC VULNERABILITY OF MASONRY BUILDINGS OF ALGIERS – ID 507

*M. Boukri, National Earthquake Engineering Centre (CGS), Algeria*
*M. Bensaibi, Civil engineering Department, Saad Dahleb Universi, Algeria*

In Algiers, especially in the oldest communes, the real park is made up mainly of masonry buildings (stone and/or brick). The expertises carried out on this frame as well as the post-seismic investigations which took place on this territory showed the low resistance of this type of construction towards seismic action. The study of the seismic vulnerability of masonry buildings is thus of topicality and constitutes a fundamental stage for the reduction of the losses due to earthquakes in the capital. This vulnerability can be reduced if preventive measures are taken. The knowledge of the state of the frame allows the decision-making as for the reinforcement of the most vulnerable structures, in other words, those presenting the most risk. In this work, we will present an estimate of the vulnerability degree of masonry buildings of Algiers by basing ourselves on the "Vulnerability Index Method". It allows to evaluate the seismic vulnerability of these buildings then to carry out their classification. Modifications were made to this method in order to adapt it to the Algerian context. Technique cards allowed the estimate of the Vulnerability Index for masonry buildings of Belouizdad commune. The developed calculation program allowed the automation of calculation and the treatment of the whole data. The analysis of the results obtained from this program enabled us to classify the buildings studied according to their seismic quality.

Key – words : Seisms, Hazard, Masonry buildings, Algiers, Vulnerability index.

## EARTHQUAKE RISK REDUCTION OF UNIVERSITY BUILDINGS – ID 522

*R. Alexe, Technical University of Civil Engineering, Romania*
*A. Calin, Technical University of Civil Engineering, Romania*
*C. Calin, Technical University of Civil Engineering, Romania*
*C. Dragomir, Technical University of Civil Engineering, Romania*
*M. Nicolae, Technical University of Civil Engineering, Romania*
*O. Pop, Technical University of Civil Engineering, Romania*
*C. Slave, Technical University of Civil Engineering, Romania*

The paper deals with university buildings located in seismic prone areas and due to the high concentration of young people are of second class of importance. Most of these buildings have been designed before the seismic codes started to be used, and in the meantime they were successively modernized by creating larger spaces with more windows and sometimes with curtain walls. The codes of seismic protection have been also in permanent progress letting the university buildings uncovered in front the menace of earthquakes. Japan and the United States already started some extensive programs of risk reduction by accordingly strengthening the buildings in danger. In the frame of a National Research Project a similar initiative just started in Romania. The paper presents seven issues of that project, each of them developed by a doctoral student, as follows: 1) The specific provisions of EC8 and National Code P100:2004 for university buildings; 2) Seismic behaviour and safety of curtain walls; 3) Preparedness of internal spaces and equipments for seismic events; 4) Identification of damages and faults in structural members with the aid of genetic algorithm; 5) Evaluation of the existing structures according to ISO 13822:2001; 6) Strengthening the nonstructural members for seismic actions without interrupting the academic activity; 7) Preparedness of external spaces, around university buildings, for post-seismic events, the recovery of damaged environment for resuming the normal academic life including. The project is scientifically coordinated by Prof. Ramiro Sofronie who also acts as a supervisor of the doctoral students. The results of this research will be used to prepare a guide manual with practical instructions for all Romanian university centres.

## ULTIMATE SEISMIC RESISTANCE OF EXISTING RC WAFFLE-FLAT-PLATE STRUCTURES. PART I: PUSHOVER ANALYSES – ID 530

*A. Catalan, University of Oviedo, Spain*
*X. Cahis, University of Girona, Spain*
*A. Benavent-Climent, University of Granada, Spain*

Reinforced concrete waffle-flat-plate structures have been used extensively in moderate seismicity areas such the southern part of Spain. Past research showed that this type of structures have low energy-dissipation capacity and high lateral flexibility. Moreover, many of these structures were designed according to old seismic codes, which required relatively low lateral strength and ductility as compared to current codes. Evaluating their ultimate earthquake resistance is an important issue for deciding whether and to which extent they need to be seismic upgraded.

This paper is the PART I of a more extensive research which aims at evaluating the ultimate seismic resistance of existing reinforced concrete waffle-flat-plate structures constructed in the southern part of Spain before 1994, according to the old seismic code PDS-74. The ultimate seismic resistance of the structure is interpreted here in terms of ultimate energy dissipation/absorption capacity (UEDC), following the Housner-Akiyama energy approach. The UEDC of the structure is the sum of the vibrational elastic energy, the energy dissipated by damping and the energy absorbed by the structure through plastic deformations. This paper evaluates the total amount of plastic strain energy that this type of structures can dissipate up to collapse. The evaluation is carried out by means of nonlinear pushover analysis. To this end, several models representing typical buildings constructed in Spain between 1974 and 1994 are subjected to various patterns of lateral loads. Several approaches proposed in the literature for performing the pushover analysis are investigated and compared.

## ULTIMATE SEISMIC RESISTANCE OF EXISTING RC WAFFLE-FLAT-PLATE STRUCTURES. PART II: DYNAMIC ANALYSES – ID 533

*X. Cahis, University of Girona, Spain*
*A. Benavent-Climent, University of Granada, Spain*
*A. Catalan, University of Oviedo, Spain*

Reinforced concrete waffle-flat-plate structures have been used extensively in moderate seismicity areas such the southern part of Spain. Past research showed that this type of structures have low energy-dissipation capacity and high lateral flexibility. Moreover, many of these structures were designed according to old seismic codes, which required relatively low lateral strength and ductility as compared to current codes. Evaluating their ultimate earthquake resistance is an important issue for deciding whether and to which extent they need to be seismic upgraded.

This paper is the PART II of a more extensive research, which aims at evaluating the ultimate seismic resistance of existing reinforced concrete waffle-flat-plate structures constructed in the southern part of Spain before 1994, according to the old seismic code PDS-74. The ultimate seismic resistance is evaluated in terms of ultimate energy absorption/dissipation capacity (UEDC), by applying the Housner-Akiyama energy approach. In this paper, the UEDC of the structure is directly evaluated through nonlinear dynamic response analyses. To this end, a series of dynamic analyses are carried out on several structures subjected to historical accelerograms. Each accelerogram is applied repeatedly with increasing peak ground acceleration until it brings the structure to collapse. At this point, the total seismic energy inputted by the earthquake is calculated.

## EFFECTS OF THE SPATIAL CORRELATION IN GROUND MOTION ON THE SEISMIC RISK OF PORTFOLIO OF BUILDINGS – ID 568

*H. Takayuki, Tokio Marine & Nichido Risk Consulting Co.,Ltd, Japan*

We have proposed the seismic risk quantification method for a portfolio of buildings, in which the risk reduction effect by diversifying the buildings is given assuming that the variability in the ground motion intensity in each site is fully correlated. Since this assumption gives the conservative results, it is required to obtain the realistic value from the viewpoint of risk management. Recently, large amounts of earthquake observation data in Japan have been utilized, so that the spatial correlations of ground motion intensities in the different sites can be calculated. In this study, abovementioned spatial correlation in the Kanto district is obtained using K-NET and KiK-net data of National Research Institute for Earth Science and Disaster Prevention, and is applied to the model portfolio of the buildings, followed by the conclusion that introducing the correlation has a large effect on the estimated losses.

## MULTI-CRITERIA DECISION MAKING FOR SEISMIC RETROFITTING OF A RC STRUCTURE – ID 606

*N. Caterino, University of Naples Federico II, Italy*
*I. Iervolino, University of Naples Federico II, Italy*
*G. Manfredi, University of Naples Federico II, Italy*
*E. Cosenza, University of Naples Federico II, Italy*

Seismic retrofitting of under-designed structures is a consolidated approach to risk management. Several options are available for the achievement of the vulnerability reduction goals, each of those having peculiar performances in respect of different technical and non-structural criteria. Selection of the "best" solution is a non-trivial task, because criteria may conflict each other. Multi-Criteria Decision Making (MCDM) methods may be useful in the matter, allowing to rank the overall performances of the set of alternatives and, therefore, to identify the "optimal" one. In the study presented herein, such approach was applied to the seismic upgrade of an old RC building, hypothesizing an update of the seismic hazard at the site where the structure is supposed to be located. Three different strategies were designed to get the required seismic performance improving: (a) ductility only, (b) strength only, (c) both in combination. Non-linear structural modeling, seismic risk analysis, criteria selection and MCDM results are also discussed.

## SEISMIC RISK EVALUATION OF THE ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE BUILDING PORTFOLIO – ID 610

*X. Mittaz, SD Ingénierie Sion SA, Switzerland*

According to the decision of the Swiss Federal Council of December 11 2001, all transformation or retrofit projects of the Swiss Confederation or subsidized by the Swiss Confederation, as well as all existing federal buildings of classes II and III must be verified for their seismic safety. If important deficiencies are found, the opportunity (proportionality) of reinforcement measures must be evaluated. For important building portfolios, such as the one of the Ecole Polytechnique Fédérale de Lausanne, it is necessary to have a methodology that enables a risk based prioritization of the buildings in order to distribute the efforts for in depth analysis and reinforcements over several decades. This prioritization procedure has to be cost efficient and rely on simple indicators. The selected methodology for the EPFL is the first step of a 3 steps methodology for the seismic evaluation of existing buildings published as recommendations by the former Federal Office for Water and Geology. In this first step, the seismic risk is grossly evaluated based on hazard, vulnerability and damage potential indices. Each index is calculated based on several indicators associated with scores. The evaluation requires no engineer calculations. The vulnerability indicators are assessed on the basis of the analysis of architectural plans and photos. The application of the method on a large portfolio costs on average 4 man-hours per building. The prioritization of the buildings is then made based on the building risk index and vulnerability index. This paper presents the results of the application of this first step evaluation for 65 buildings of the EPFL portfolio. This study will be the basis for defining the priorities for in depth evaluations. For higher risk buildings, the in depth evaluations will be done rapidly. For lower risk buildings, the in depth evaluations will wait eventual important transformation or retrofit projects.

## PREDICTION OF SEISMIC RESPONSE OF EXISTING ASYMMETRIC RC STRUCTURES – ID 667

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze,*

*Italy*
*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Tanganelli, Dipartimento di Costruzioni, Università di Firenze, Italy*

In light of current knowledge in earthquake engineering and of the most advanced seismic code provisions, most reinforced concrete buildings realized in the Italian seismic areas, starting from the 50's until the middle of '70s, are under-designed with respect to seismic loads and, very often, also with respect to static loads only. Recently, the issue of a new Italian seismic code has resulted in an extensive program for seismic assessment of strategic and relevant buildings, particularly the school buildings. A remarkable case is represented by the school building of Londa, a small town near to Florence, built in 1974. For this building a complete information about material properties and structural characteristics is available since the Seismic Department of the Region of Tuscany has started a large program for assessment of seismic vulnerability of existing RC public buildings, based on destructive and non destructive tests. The structural organism of this building, which is rather irregular, presents many seismic vulnerability sources, originated by design and construction errors, together with the problem of a low concrete strength. In this paper, the seismic response of such structure is analyzed both by means of nonlinear dynamic analysis and by means of pushover analysis. In order to use pushover analysis for predicting seismic response of an irregular structure, special procedures need to be used, since effects of torsional response become important. The method proposed by Fajfar, which constitutes an extension of the well-known N2 method, appears very promising and it is used in this paper to improve ability of pushover analysis to predict response of such an irregular structure. It is found that the structure can resist extremely low intensity earthquakes and that the extension of N2 method fails to predict conservatively the shape of displacement envelope at the building stiff side.

## EVALUATION OF EARTHQUAKE RESISTANCE AND THE STRENGTHENING OF BUILDINGS DAMAGED BY EARTHQUAKE – ID 673

*M. Danieli, College of Judea and Samaria, Israel*
*J. Bloch, Judea and Samaria, Israel*

This paper presents an original method of the quantitative analysis of earthquake resistance of buildings damaged by an earthquake. Over 25 factors influencing seismic resistance of buildings are considered. These factors can be divided into two groups: general common factors for various types of buildings which reflect the main standard requirements; and specific factors applied to different types of buildings. Each factor includes three parameters: a "weight" for securing seismic resistance; a variable which causes the factor to conform to standard seismic requirements; an evaluation of damages. Each of the above parameters is analyzed numerically and its gradation is established. The value of a parameter may vary between 0-1. The value of the parameter is estimated according to conformity to seismic standards for building requirements. The total factors and their parameters are organized into two tables. The first table contains factors which are common to different structures and reflect general rules for seismic design. The second table presents different factors pertaining to different structures. An analysis is performed on the basis of the above data resulting in a value of seismic resistance of the building computed in a quantitative expression. Parts of the unit gradation allow the tables to be used to determine "weak points" in the building thus enables the enhancement of seismic resistance of the damaged building. Parameter tables and a form of a statement have been prepared during the implementation of this work. A characteristic building has been chosen, appropriate measurements have been made and data was collected. An analysis of the seismic resistance has been performed on this building in accordance with the method discussed herein. Detailed schemes for reparations have been prepared for it. Finally, computations have been made to evaluate the seismic resistance of the buildings after the recommended strengthening has been completed.

## SEISMIC RISK OF HIGH-RISE BUILDINGS IN MAJOR CITIES OF CENTRAL BALKAN REGION DUE TO DISTANT EARTHQUAKES – ID 686

*T. Petrovski, IZIIS, Macedonia*
*J. Petrovski, IZIIS, Macedonia*

Presented are seismic hazard and damaging effects of the earthquakes generated from Pehcevo-Kresna seismic source zone, where on April 04, 1904 an earthquake occurred, with the largest magnitude of M=7.8 ever recorded on the continental part of the Balkan Peninsula. Damaging effects of Pehcevo-Kresna Earthquakes of April 04, 1904 were experienced over an area of about 200,000 square kilometers, with total destruction and heavy damage of low rise buildings in the epicentral region of about 20,000 square kilometers with macroseismic intensities of 8 to 10 (MSK-64). Recently developed seismic hazard maps of Central Balkan region present very high level of expected peak ground accelerations in the range of 0.70g in the epicentral region to 0.15g on a distance 150-200 kilometers, generated from Pehcevo-Kresna seismic source zone. Assessment of site specific seismic hazard is presented for the major urban areas in the region like Sofia (epicentral distance 107 km), Thessalonica (123 km), Skopje (146 km) and Nish (205 km), confirming similar high levels of peak ground accelerations. Dominant frequency content and spectral characteristics of selected distant earthquake records are presented and discussed with consideration of long period damaging effects on high-rise buildings and structures. Historic evidence shows that distant earthquakes did not produce damage to low-rise buildings dominantly present in the past history in urban and rural regions with high seismic exposure to distant earthquakes. Long period damaging effects due to distant earthquakes have been analyzed on the selected high-rise buildings at the sites of the city of Sofia, Thessalonica, Skopje and Nish, implementing the criteria for regular and essential facilities. As it is presented, high-rise buildings and structures will be exposed to amplified earthquake ground motions due to resonance effects, producing heavy damage and complete failure, if the buildings are not designed to long period damaging effects of distant earthquakes.

## SEISMIC VULNERABILITY ASSESSMENT OF SCHOOL BUILDINGS – ID 691

*C. Bhakuni, ABS Consulting, UK*

A methodology for evaluating the seismic vulnerability of school buildings in a given region is presented here. The tool is one of the cost effective, quick and reliable methods, and can be usefully adopted for schools at different geographical regions with high levels of seismicity that require immediate action. The method primarily involves a visual survey based examination of school buildings on the basis of their structural modification parameters. The vulnerability levels are evaluated for the structure types based on lateral load resistant system, and utilising the European macroseismic (EMS-98) scale classifications and school population figures. Four levels of vulnerability are proposed in this method. This methodology as an assessment tool was tried and tested in 160 schools in three largest cities of Gujarat, India. It was found out that the results are not only helpful in defining the risk levels but also sets the scene for priority mitigation activities such as retrofitting, training needs etc and hence establishing an overall mitigation strategy for school building safety in a region.

## COMPARISON BETWEEN NUMERICAL ANALYSES AND OBSERVED SEISMIC DAMAGE OF ANCIENT BELL TOWERS. – ID 787

*E. Curti, DISEG, University of Genoa, Italy*
*S. Lagomarsino, DISEG, University of Genoa, Italy*
*S. Podestà, DISEG, University of Genoa, Italy*

The post-seismic damages observation of slender masonry buildings points out the need to carry out a forecast of their seismic response. The surveyed damage is not possible to correlate with

the typological and constructive details of such structures. If we schematize slender structures as a single degree of freedom, characterized by a low natural frequency, we could deduct that, for the high slenderness, this kind of buildings is able to attenuate the energy of seismic input, reducing the damage level. Such approach, nevertheless, does not prove by the post-seismic observations which often put in evidence high damage level above all in the upper part. A preliminary motivation of this different behaviour can be find in the rough simplification connected to the single degree of freedom model adopted. These structures, in fact, are continuous system; the mass is regularly distributed in height and therefore difficultly schematized as a single degree of freedom model. They determine, through a filter of seismic actions, an amplification of the periods near to the natural frequencies that can be significant for the upper part of the structure. In the submitted paper, in order to forecast the seismic response of these structures, the bell tower damaged data after the Friuli earthquake in 1976, were analysed. The sample is characterized by several isolated structures and this features allowed us to distinguee the cases in which the damage was localized only in the bell tower or in the belfry, without taking into account the interactions with the church. On the basis of dimensional available data, numerical analyses have been performed. The comparison between the results of numerical analyses and the observed damage has allowed to define a methodology for the foresee of the bell tower seismic response.

## HOLISTIC SEISMIC RISK EVALUATION FOR AN URBAN CENTRE – ID 840

*M. L. Carreño, Technical University of Catalonia, Spain*
*O. D. Cardona, Universidad Nacional de Colombia, Colombia*
*A. Barbat H, Technical University of Catalonia, Spain*

In the past, the concept of risk has been defined in a fragmentary way in many cases, according to each scientific discipline involved in its appraisal. At nowadays, the risk is defined, for management purposes, as the potential economic, social and environmental consequences of hazardous events that may occur in a specified period of time. From the perspective of this article, risk requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties or economic losses (direct impact), but also the conditions related to social fragility and lack of resilience conditions, which favour the second order effects (indirect impact) when a hazard event strike a urban centre. The urban seismic risk evaluation is proposed from a holistic point of view; that is, an integrated and comprehensive approach to guide decision-making. Evaluation of the potential physical damage (hard approach) as the result of the convolution of hazard and physical vulnerability of buildings and infrastructure is the first step of this method. Subsequently, a set of social context conditions that aggravate the physical effects are also considered (soft approach). In the method here proposed, the holistic risk evaluation is based on urban risk indicators. According to this procedure, a physical risk index is obtained, for each unit of analysis, from existing loss scenarios, whereas the total risk index is obtained by factoring the former index by an impact factor, based on variables associated with the socio-economic conditions of each unit of analysis. Finally, examples of the model application are given for two urban centres: Bogotá and Barcelona.

## NUMERICAL TOOL TO STUDY STRUCTURAL REINFORCEMENT OF RC FRAME JOINTS USING FIBER REINFORCED POLYMERS – ID 844

*X. Martinez, UPC, Spain*
*S. Oller M, UPC, Spain*

Strengthening or retrofitting existing structures in order to increase their ductility and improve their seismic response has traditionally been accomplished using conventional materials and construction techniques. Composite materials made of fibres in a polymeric resin (FRP) have emerged as an alternative to these methods. To view the influence of these reinforcements when seismic loads are applied, this work studies the structural response of frame joints when an horizontal load is applied to them. Under a seismic load, joints are one of the weakest parts of the structure. The response of a plain concrete frame joint is compared with the response obtained when it is reinforced using FRP. Different configurations of FRP reinforcements are considered to compare their behaviour. The structural response of all structures considered is obtained with a numerical simulation. This is done using the finite element method. Composites are treated using the mixing theory, which obtains the composite behaviour from the material properties of all its components. Each component is simulated with its own constitutive equation. The anisotropy usually found in composite components is treated using a mapped space theory. The debounding effects found in composite materials are treated using the formulation developed by E. Car and S. Oller. The frame and its joint have been studied using two-dimensional and three-dimensional models. The results obtained validate the use of FRP reinforcements to improve joint frames seismic response. The structure load capacity is increased in a 20% when lateral reinforcements are applied to the joint. The reinforcement capacity is far from its end when the joint fails due to tractions in concrete. This can avoid the structure to collapse in a seismic case. They results also show a good performance of the numerical tool developed.

## SEISMIC RISK ASSESSMENT OF REINFORCED CONCRETE STRUCTURES – ID 882

*X. Romão, FEUP, Portugal*
*J. Guedes, FEUP, Portugal*
*A. Costa, UA, Portugal*
*R. Delgado, FEUP, Portugal*

Probabilistic approaches aiming to design or to assess, as opposed to deterministic ones, are seen as superior means of measuring the performance of structures under earthquake loading. For seismic risk assessment of structures, probability based methodologies may be divided into two main categories. A first one dedicated to global risk assessment of structures located over an entire urban area, usually based on simplified approaches and analysis methods which allow for the rapid assessment of a large group of structures. The second category includes methods which are dedicated to the risk assessment of individual structures. Methodologies of this second category are more detailed and usually consider more advanced methods for structural analysis. These methodologies are mostly based on the results obtained from the numerical analysis of a model representing the structure under study for various earthquake representations (accelerograms) of increasing intensity. The probabilistic treatment of those results combined with the probability of occurrence of the selected ground motion intensities will enable the calculation of the probability of failure of the structure. The proposed paper will present a methodology that fits in this category, focussing on its main aspects, and an application to the seismic risk assessment of a reinforced concrete building. The application will focus on the importance and the effects on the final values of the probability of failure, in particular on the selection of the ground motion intensity measure, the scaling of the accelerograms, the different forms of characterizing the best estimate and the dispersion of the structural response at a given ground motion intensity level, and the consideration of ground motion variability and randomness of the material properties.

## SEISMIC BEHAVIOUR OF OLD CONCRETE – ID 939

*V. Levtchitch, Frederick Institute of Technology, Cyprus*
*V. Kvasha, National University-Lvivska Polytechnica, Ukraine*
*H. Boussalis, California State University, United States*
*A. Chassiakos, California State University, United States*

The aim of this study is to obtain, expand and verify some data needed for the performance analysis of existing reinforced concrete structures. Static, dynamic and low cycle fatigue testing of 23-27 years old concrete has been carried out. Cylindrical core samples have been drilled from residential buildings in Nicosia, Cyprus. New concrete of identical composition has been prepared and tested at 28 days. Assessment of compressive and tensile strength, modulus of elasticity, stress-strain relationship, plastic

strain capacity, dynamic strengthening and low cycle fatigue behaviour have been considered. Static compressive strength increase was found to be 3-15%, which is substantially lower than commonly anticipated values. There was practically no increase of static splitting strength. Elastic modulus increase was considerably larger (25%-35%) than that of strength. Up to the stress of 75% of a peak value concrete remained elastic. Dynamic strengthening was 2-4 times lower than that of 28 day concrete. Dynamic strengthening in splitting was 2-3 times lower than that in compression. Ultimate strains were 40%-50% smaller than those of young concrete. A few initial cyclic loadings bring rapid changes and the effect of dynamic strengthening is fast disappearing. At 200 cycles of loading the fatigue limit is 0.8 of the static strength. So, the large seismic strengthening commonly used in analysis is in conflict with the real phenomenon. Tensile-compressive strength ratio is dramatically decreasing. A contribution of concrete in resisting shear and torsion and the effectiveness of confinement are all diminishing. The ignoring of concrete age can result in a dramatic overestimation of its seismic capacities. Proposals for the evaluation of dynamic strengthening, low cycle fatigue limit, modulus of elasticity and ultimate strains have been formulated.

## PROBABILISTIC SEISMIC HAZARD ANALYSIS WHICH DISTINGUISHES BETWEEN ALEATORY AND EPISTEMIC RANDOMNESS – ID 944

*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*

In a country like Italy, directly affected by seismic phenomena, the assessment of vulnerability and seismic hazard in the entire territory plays a very important role, in order to minimize seismic effects on the population. In this paper two procedures for the Probabilistic Seismic Hazard Analysis (PSHA), i.e. the probability functions (CDF: cumulative distribution function and PDF: probability density function) of a selected ground motion parameter (e.g., peak ground acceleration, peak ground velocity, peak ground displacement, spectral acceleration, ...) at a specific site, over a given observation time, are analytically developed and elucidated. Both procedures are developed according to Cornell's widely upheld approach (1968). The first procedure is characterized by the treatment of the distance R from the epicentre to the site as a continuous random variable, while the other treats R as a discrete variable. Both procedures lead to closed-form analytical expressions for the PDF and CDF of the selected ground motion parameter and its prediction, thus distinguishing between (i) the randomness of the prediction due to the time and space stochastic processes which govern the occurrence of seismic events and (ii) the randomness due to the intrinsic variability of the data and the error due to the attenuation model. This distinction between aleatory and epistemic randomness has been advised in the more recent scientific contributions in the field. The paper also presents illustrative examples of application of the two procedures to the Italian territory for the determination of the probability functions of the peak ground horizontal acceleration for selected Italian sites.

## ASSESSMENT OF SEISMIC PERFORMANCE FOR HOSPITAL SYSTEMS – ID 981

*G. Lupoi, University of Rome "La Sapienza", Italy*
*P. Franchin, University of Rome "La Sapienza", Italy*
*A. Lupoi, University of Rome "La Sapienza", Italy*
*P. E. Pinto, University of Rome "La Sapienza", Italy*

A methodology for the probabilistic assessment of seismic performance for hospital systems is presented. Hospital systems are a typical example of social systems, for which the performance results from the interaction of human, organisational and physical components. Further, past experiences have shown that hospitals are particularly vulnerable systems, mainly due to their own complexity, to their need for basic and critical supplies and to their high level of occupancy.

The methodology meets two main challenges of performance assessment procedures: it gives adequate consideration of all different sources of uncertainty (structural, capacity models, earthquake) and it defines a meaningful performance measures for the system under consideration. This measure, called hospital treatment capacity (HTC), has been derived on the basis of the analysis of past experiences and responses of hospital systems, and allows the quantification of the amount of services provided by the hospital following an earthquake in terms of number of patients that can be given surgical treatment. The HTC is composed by three factors,alfa, beta and, gamma, accounting for: the efficiency of the emergency plan, the preparedness of the personnel and the physical resources available, respectively.

The results consist in a 2nd moment characterisation of the random variable HTC and, if the Health Treatment Demand (HTD, number of patients that require surgical treatment) is known, in the estimation of the risk that HTC<HTD.

The methodology employs a limited number of non-linear dynamic analyses to establish a functional relationship between structural and non-structural damage and the examined intensity levels.

The application to a real hospital system in a highly seismic region of Southern Italy demonstrates the validity of the suggested methodology as an effective tool to point out the most critical components of the system and to evaluate alternative mitigation strategies.

## SPATIAL AND TEMPORAL TRANSLATION OF VULNERABILITY MODELS FOR REINFORCED CONCRETE BUILDINGS – ID 988

*G. Trendafiloski, IZIIS, Macedonia*
*Z. Milutinovic, IZIIS, Macedonia*

The preparation of an earthquake scenario should include regionally-based vulnerability functions developed on the base of: 1) the data from past earthquakes (macroseismic approach) or different analytical methods (mechanical approach); or, 2) calibration of the existing functions. Various calibration techniques are proposed recently and the mostly used are those using the data from past earthquakes. However the existence of a homogenous earthquake data set is not always the case and it is necessary to use different approach for the stated needs. A method for spatial and temporal translation of vulnerability models is recently proposed. It is based on the aseismic design codes in the region of interest since it is assumed that if they are strictly followed in the construction practice, the seismic performance and level of damageability of building are "controlled by them". Two basic factors are considered: 1) the design base shear; and, 2) the ultimate deformation capacity of buildings. The referent vulnerability model is translated / calibrated to target vulnerability model through combination of a shift and rotation quantified by the differences in the building codes and construction practices. The proposed method is used to perform spatial translation of vulnerability models in different regions in Europe - case study: Portugal and Former Yugoslavia. Based on the comparison of the target vulnerability model for reinforced concrete (RC) moment resisting frame building and the existing one, it is concluded that the proposed method can be used to perform reasonable translation of vulnerability models for same/similar building types. Lately, a temporal translation of vulnerability models has been performed to develop corresponding Eurocode 8 (EC-8) based vulnerability models for: 1) RC moment resisting frame (RC1); 2) RC shear wall (RC2); and, 3) RC dual system (RC4) buildings.

## STUDY ON SEISMIC RETROFIT OF AN EXISTING BUILDING WITH SOFT AND WEAK GROUND-FLOOR IN ROMANIA – ID 1008

*T. Kaminosono, NCSRR, Romania*
*A. Mikame, NCSRR, Romania*
*R. Vacareanu, NCSRR, UTCB, Romania*
*A. Pretorian, UTCB, Romania*
*K. Sasai, Fujita Corp., Japan*

There are many existing vulnerable buildings which are apartment houses with a soft and weak ground-floor built after late 1950s and prior to the March 4, 1977 earthquake in Romania.

This building typology consists of a dual structural system in the vertical direction. One is a RC framed system in the ground floor and another is RC shear wall system in the upper stories. The major vulnerabilities of this building typology come from 1) Concentration of most of induced seismic energy in the ground floor, 2) Concentration of most of seismic lateral displacement in the ground floor, 3) Insufficient ductility for RC columns in the ground floor, and 4) Insufficient shear capacity for both RC columns and RC upper shear walls

In order to demonstrate the vulnerabilities and applicability of some retrofitting techniques static and dynamic nonlinear analyses for seismic capacity evaluation and seismic retrofit design of an existing building, which has 11 stories with a soft ground-floor, based on Japanese seismic design procedure are implemented. In the nonlinear static analyses push-over limit analyses is adopted and in the nonlinear dynamic analyses the wave motion produced by 1977 Vrancea Earthquake in Romania is applied. Regarding the retrofit techniques installation of shear walls and oil dampers are studied.

From these analyses following results are obtained. 1) Concentration of most of seismic lateral displacement in the ground floor was confirmed. 2) Insufficient shear capacity for both RC columns and RC upper shear walls was confirmed. 3) Dynamic response for shear force in the upper floors after retrofit in the ground-floor was increased comparing to that of existing structure before retrofit. 4) It is suggested that the seismic retrofit should be necessary not only in the ground-floor but also in the upper floors.

## SEISMIC STRENGTHENING OF STATE BUILDINGS: GOVERNMENT OFFICE OF DATCA, TURKEY – ID 1012

*H. Kaplan, Pamukkale University, Turkey*
*S. Yilmaz, Pamukkale University, Turkey*
*Y. S. Tama, Pamukkale University, Turkey*
*E. Akyol, Pamukkale Universitesi, Turkey*

A large amount of vulnerable state buildings in Turkey, suffered from earthquake induced damages during last 14 years by 1992-Erzincan, 1995-Dinar, 1999 Kocaeli and Duzce, 2003-Bingöl Earthquakes. There exists many studies on these damages and their reasons in the literature. These studies agrees on that damages are manly results from inadequate workmanship, detailing and material strength. Besides, those structures damaged due to inappropriate structural system formation and soil conditions. In this study, Seismic vulnerability assesment of 5 blocks of Datca Governmet Office is done. In their current state, material properties and structural system have been determined. After the investigations structures are reported as vulnerable to seismic forces. For the blocks, seismic strengthening projects are prepared. As there is no alternative, buildings have to be used during the construction works. Therefore, different strengthening strategies are applied to the blocks. For example, some of the blocks are strengthed from outside of the building by external shear walls allowing the use of block. Coupling beams are constructed to reduce required amount of shear walls in a 6 storey block. At the end of the study, different strengthening strategies are proposed. Details of those are explained.

## THE FIRST ISRAELI CODE FOR SEISMIC RESISTANCE ASSESSMENT AND STRENGTHENING OF EXISTING BUILDINGS: STRUCTURE, PRINCIPLES, APPROACH – ID 1057

*A. Scarlat, Ben-Gurion University, Israel*
*E. Leibovich, Sami-Shamon-College, Israel*

INTRODUCTION: The code comprises two main chapters: I.Methods for the seismic resistance assessment of existing buildings. to their degree of accuracy. Three levels of methods are proposed, depending on their degree of accuracy. II.Principles for strengthening, including an "open catalogue" with examples of details dealing with different structural elements (to be periodically completed). By taking into account that the number of buildings to be checked is very high, accurate seismic analyses are practically impossible to be generally used; therefore we have to use approximate methods, at least in a first stage, in order to "filter" the buildings according to their seismic resistance and to make use of accurate methods only for the most dangerous ones. Since we had no financial possibilities to carry out tests on a large scale, we decided to choose as basic criterion to validate the proposed formulae (either ours, or taken from technical literature) – the results should be close to those yielded by the Israeli code 413/95, intended for seismic design of new buildings. The code applies only to buildings up to 12 stories and buildings positioned at more than 50 m from a fault. It does not deals with buildings on soil exposed to liquefaction (the criteria for identifying such soils are yet under discussion).

LEVEL I (STATISTICAL METHOD): The evaluation has to be performed during a short lapse of time and only minimal documentation be needed.

LEVEL II (1ST SCREENING): The proposed method yields a higher degree of accuracy, which permits to use it in order to evaluate the seismic resistance of a specific building.

LEVEL III (ACCURATE ANALYSIS): We assume that an analysis carried out to the Israeli Code 413/95 is an accurate one.

## ANALYTICAL ESTIMATION OF VULNERABILITY FUNCTIONS FOR R.C. STRUCTURES – ID 1066

*A. Eleftheriadou, Demokritus University of Thrace, Greece*

Earthquake loss estimation is a recently developing field. The need for a reliable estimation of the socio-economic impact of earthquakes was emphasized after major earthquakes and their catastrophic consequences.

This paper presents a methodology for the analytical estimation of structural vulnerability of reinforced concrete structures. The methodology includes development of fragility curves, expressing the probability for a structure to sustain different degrees of damage at given ground motion levels. For this purpose, the seismic response of an actual building that collapsed in the 1999 Athens Earthquake is obtained analytically by nonlinear pushover analysis. The building was a standard moment resisting structure designed and built according with earlier design codes, and was non-conforming to modern seismic detailing requirements. Spectral displacement is used as a measure of earthquake intensity. Uncertainty in ground motion is accounted for through the use of suites of accelerograms with characteristics that are representative of the hazard level (Vamvatsikos and Cornell, 2002, 2005). Unlike assessing the performance of structures for a given ground motion hazard level, the structural demand hazard curve provides multi-objective structural performance information, which has been integrated from all possible ground motion hazard levels. Inter-storey drift is used to determine the damage state of the building at the performance point. The range of values of damage index at each performance level is defined. Results of the assessment procedures are used to construct vulnerability curves for the specific structural building type. Vulnerability curves can be regarded as a basic tool in estimating the expected damage of a future earthquake.

In this way a complete risk assessment tool with a high degree of confidence can be applied to a wide range of structures namely reinforced concrete buildings representative of the pre-1980s design framework. The methodology developed in this paper can be extended to additional structure types.

## NONLINEAR ANALYSIS OF GRAVITY DESIGNED RC FRAMES CONSIDERING VARIOUS FAILURE MODES – ID 1069

*N. Kyriakides, University of Sheffield, UK*
*K. Pilakoutas, University of Sheffield, UK*

The vast majority of reinforced concrete (RC) buildings in earthquake prone zones were designed prior to the enforcement of national aseismic codes. Thus, these buildings lack the special detailing required for capacity design, which is nowadays regarded as standard practise in seismic regions.

Due to these deficiencies in design, the damage patterns observed, in most cases, include shear failures in members and joints, pullout failures due to reinforcement slip and buckling failures in columns.

The main reasons for these undesirable brittle failures is the lack of adequate amount and spacing of transverse reinforcement, inadequate development length of longitudinal bars, insufficient anchorage of longitudinal bars in joints and of transverse reinforcement. Therefore, the analysis of these under-designed buildings should be able to accommodate all the above deficiencies.

In this paper an attempt is conducted to simulate the results obtained from a shaking table test of an RC frame, designed according to an old Italian code without seismic provisions. The frame was tested for various acceleration levels. Emphasis will be given on the damage patterns, which were concentrated in the joints. Further on, the structural modelling of the frame members will be presented highlighting its ability to account for the above mentioned failure modes. Degradation in shear and bond capacity can also be applied both in strength and stiffness making the model even more applicable for seismic analysis.

The comparison of the analysis results with the experimental ones will show the improvement in predicting the actual seismic performance, and most importantly the failure mode, when using sophisticated models as opposed to using simple hinge elements.

## RETROFITTING STRATEGIES FOR RC EXISTING BUILDINGS – ID 1072

*C. Faella, Dept. of Civil Engineering, University of Salerno, Italy*
*D. De Santo, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Martinelli, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Nigro, D.A.P.S., University of Naples Federico II, Italy*

A great part of the existing RC structures built in Italy and across the Mediterranean basin have been designed without considering seismic-induced actions and seismic criteria for strength and ductility design. Seismic assessment of non-seismically designed RC structures generally evidences their structural deficiencies related to a general lack of strength and ductility of either the most engaged members or the structural system as a whole. Retrofitting is generally a need for such structures and various technical solutions can be considered for improving their seismic performance according to suitable objectives depending, as usual, upon the building use (residence, office, school, hospital and so on). These possible technical solutions for seismic retrofitting of existing buildings, partially derived by the seismic protection techniques for new structures, can be classified as follows depending upon the kind of action provided in the retrofitted structure: - capacity upgrading, that can be obtained by improving cross-section and member capacity in terms of both strength and ductility, either through traditional materials, such as steel, or innovative ones, like FRPs; - demand reduction, that can be pursuit by introducing additional sub-structures conceived to work in parallel with the existing structure and to reduce their engagement due to the expected seismic action. Although plenty of studies, both theoretical and experimental, have been carried out in the last two decades for proposing several technical solutions for seismic protection of civil structures, but no general strategies have been proposed for choosing among such techniques the optimal ones, both under the technical and economical standpoint, depending on the existing structures typology and retrofitting objective. Therefore, the present paper is mainly devoted to study this aspect in order to formulate general criteria for choosing the best retrofitting solution among the possible ones belonging to the classes introduced above.

## SEISMIC VULNERABILITY AND STRENGTHENING OF A MODERN ARCHITECTURE BUILDING – ID 1079

*H. Rodrigues, University of Aveiro, Portugal*
*A. Costa, University of Aveiro, Portugal*
*H. Varum, University of Aveiro, Portugal*

In Portugal, at the end of the World War II, a new generation of architects emerged, influenced by the Modern Movement Architecture. They worked with new typologies, such as multifamily high-rise buildings, reflecting the principles of the Modernity and with a strong formal conception inspired in the International Style's codes. In the fifties, it was built a large number of Modern housing buildings in Lisbon, with particular structural characteristics that, in certain conditions, can induce weaknesses in structural behaviour, especially under earthquake loading. For example, the concept of buildings lifted in "pilotis", present in this architectural style, can strongly facilitate the occurrence of soft-storey mechanisms, which makes these structures very vulnerable to earthquake actions. The available refined numerical tools, in combination with assessment procedures make feasible the structural safety assessment of existing buildings. To investigate the vulnerability of this type of construction, one building, representative of the Modern Architecture, in Lisbon, was studied. The available information on the structural was studied. Tests on materials and natural frequencies measurement were performed. The building was studied with a non-linear dynamic analysis program, PORANL, which allows the safety evaluation according to recently proposed assessment procedures. Additionally, it was proposed and analyzed a retrofitting solution, to improve the seismic performance, based on a bracing system with a damping device associated.

## A SYSTEMS APPROACH TO THE SEISMIC PERFORMANCE ASSESSMENT OF FRP STRENGTHENED URM INFILL PANELS – ID 1102

*J. Davis, University of Bristol, UK*
*C. Taylor, University of Bristol, UK*
*E. Marashi, University of Bristol, UK*
*L. Dihoru, University of Bristol, UK*
*M. Dietz, University of Bristol, UK*

This paper will set out a risk-based, soft systems process framework for developing and evaluating the seismic performance requirements of a building structure, using FRP strengthened URM panels as a case study.

The systems framework sets out processes that:

(i) Identify a state space model of the system in which the system's performance is described in terms of key performance indicators that, in turn, are derived from the fundamental state variables of the system and are unambiguously linked to the controlling parameters of the system. (ii) Identify and harmonise the various, and sometimes conflicting stakeholder requirements, and express these in terms of the state variables identified in (i). (iii) Instantiate the actual, or forecast, system state and capacity, in terms of the state space model of (i), using numerical simulations, measurements or observations of prototype system response, or any other appropriate method. (iv) Compare the required system performance with the actual or forecast performance using an hierarchical interval probability approach, which enables the integration of objective and subjective information and the direct representation of assessment uncertainties.

As an example, the framework will be applied to the seismic safety assessment of FRP strengthened URM panels, using information from non-linear analyses, shaking table tests of full-scale panels, and expert opinion.

An important feature of this systems framework is its generality and scalability. It can be applied to the safety or general performance assessment of a wide range of systems (including highway networks, dam and water supply systems, a whole electricity supply industry, as well as detailed components) for any form of external scenario, be it seismic, wind, climate change, economic etc. It provides a practical means for building knowledge and integrated perspectives of complex dynamic systems.

## ENHANCEMENT OF JOINT RESISTANCE BY CFRP STRENGTHENING – ID 1120

*P. Papastergiou, University of Sheffield, UK*
*N. Kyriakides, University of Sheffield, UK*
*K. Pilakoutas, University of Sheffield, UK*

Corrosion and natural phenomena, such as earthquakes or even bad design, eventually decrease the designed capacity of buildings. Hence, at some point during the lifetime of a structure, new analysis may be required to strengthen weakened elements.

This paper focuses on the potential damage patterns of RC joints and the strengthening enhancement provided by Carbon Fibre Reinforced Polymers.

The study is based on a full scale shaking table test of a RC building, tested for various acceleration levels before and after strengthening was applied. The specimen was designed with no seismic provisions, targeting shear deficiency mainly in joints. These deficiencies became obvious at acceleration of 0.4 g on the bare frame, and afterwards minimal application of CFRP was applied in an arrangement aiming to increase joints' shear capacity.

Further on, dynamic non linear analysis was conducted on the retrofitted frame using a sophisticated model for the strengthened joint performance. This model accounts for both the enhanced shear capacity of the joints and their corresponding ductile behaviour. The results of this analysis are compared with the experimental ones providing sufficient correlation. The last part of the paper examines the increase in energy dissipation provided by the strengthening technique which alters the failure mechanism from brittle in joints to ductile in beam hinges.

### IMPROVING THE QUALITY OF EXISTING BUILDINGS THROUGH REPAIR, STRENGTHENING, RECONSTRUCTION AND REVITALIZATION – ID 1141

*Z. Bozinovski, IZIIS, Macedonia*

For the last decade, intensive activities on reconstruction, repair as well as enlargement and building of other storeys on existing old residential buildings has been carried out. The reasons for such an extensive reconstruction and building of other storeys onto old residential structures are the increasing need of residential area, revitalization and repair of structures and improvement of the quality of living of the occupants. However, this poses a problem since the existing structures are designed in different time and with different resistance to seismic effects. The interventions that are being done on residential structures include openings in the bearing walls, enlargement of balconies and enlargement of structures in both directions.

To avoid uncontrolled damage and loss of material goods and human lives in the event of a possible earthquake, an urgent coordinated activity of the technical and administrative potential of the country is necessary to introduce stability of the existing residential fund that will be at an acceptable and legislatively defined level through repair, strengthening and revitalization according to the extent of damages and the level of resistance of the structures under gravity and seismic effects. In the case of enlargements and building of other storeys, there is a need of a complex analysis of strength, rigidity and deformability of the existing and the new structural system for the purpose of designing and constructing an integral system with controlled and dictated ductile behaviour during occurrence of strong earthquakes.

The newly designed and the existing structures are often with completely different characteristics and behaviour under dynamic loads. In conclusion, dynamic response of the enlarged structure to seismic effects on the considered site (with their intensity and frequency content) should be controlled.

In the paper some particular problems and solutions will be described.

### ALTERNATIVE RETROFIT STRATEGIES FOR PRE-70 R.C. BUILDINGS: VULNERABILITY MODELS AND DAMAGE SCENARIOS – ID 1148

*S. Giovinazzi, University of Genoa, Italy*
*S. Pampanin, University of Canterbury, New Zealand*
*S. Lagomarsino, University of Genoa, Italy*

The inherent seismic vulnerability of existing R.C. buildings, designed prior to the introduction of adequate seismic code provisions in the early/mid-1970s, has been dramatically confirmed by the catastrophic socio-economical consequences of earthquake events occurred worldwide in the past decade. As a natural reaction, a revitalized interest on the development of seismic assessment methodology and modelling techniques, as well as on the development of advanced while viable retrofit solutions for under-designed structures, has been observed and promoted in order to identify viable risk mitigation strategies. Several alternative seismic retrofit/rehabilitation solutions have been studied in the past, few of which have been successfully implemented in practical applications on single buildings. However, due to the typical one-off peculiarity of a retrofit intervention, issues of costs and invasiveness and practical implementation still remain the most challenging aspects for their wide adoption. Recent developments and numerical/experimental validation of viable and low-cost retrofit solutions for pre-1970 buildings within a multi-level retrofit strategy approach, suggest the possible implementation at a urban or territorial scale of "standardized" solutions. In this contribution, the efficiency of such a structural mitigation strategy will be investigated, within the framework of a seismic risk analysis approach. To this aim refinements of the models typically adopted for territorial scale vulnerability assessment will be suggested to account for the peculiar alternative damage limit states and collapse mechanisms of pre-1970 R.C. buildings typologies before and after retrofit intervention, as recently observed in numerical and experimental investigations. Comparative evaluation of the reduced level of the expected damage after alternative retrofit solutions will be carried out and described in terms of fragility curves. Further exemplification of the effects of retrofit strategies planned at a territorial scale will be provided via damage scenarios referred to a case study.

### DEFINING VULNERABILITY OF A SINGLE STRUCTURE – ID 1156

*K. Peker, Erdemli Ltd., Turkey*
*A. Kaptan, Erdemli Ltd., Turkey*

Identification of vulnerability of a mass building stock is vitally important in preparation of major disaster management and mitigation strategies.

However for those who are living in this "stock of buildings" it is vital to know "What will happen when the big one hits?"

The answer of this question will depend on many important and sensitive assumptions that can not be exactly calculated.

Science of earthquake engineering is trying to find the exact answers of most of these questions, but whilst there exist a strong need to define the vulnerability of a single structure with fast and reliable methods.

The authors will present a method applicable to a single structure, based on the HAZUS99 fragility curves and hazard definitions.

Verification of this method will be presented on 10 selected buildings of separate social function classes, based on observed damages during Ms=7.4 1999 Kocaeli Earthquake.

Periods defining loss of services is calculated based on ATC13 methodology and are compared with real periods to restart services at sites.

Injury-fatality rates during the EQ hazard for the selected sites are calculated based on FEMA227 and also presented on tables compared by real recorded injuries and fatalities.

### EARTHQUAKE ANALYSIS OF A THREE STOREY BUILDING DAMAGED IN THE JUNE 2000 EARTHQUAKES IN SOUTH ICELAND – ID 1190

*F. G. Sigtryggsdottir, VST Consulting Engineers Ltd., Iceland*
*E. V. Valmundsson, VST Consulting Engineers Ltd., Iceland*
*S. Bjarnason, VST Consulting Engineers Ltd., Iceland*

In June 2000 South Iceland was struck by two destructive earthquakes. Subsequently, extensive damage evaluation was carried out for Iceland Catastrophic Insurance (see paper on: Evaluation of building damages in the June 2000 earthquakes in South Iceland). The data collected provided opportunity to compare actual damage to results from earthquake analysis of selected buildings.

A three storey reinforced concrete office building, damaged in the earthquakes, was singled out to be further analyzed applying routine design office procedures, in accordance with the pertinent Eurocodes in addition to time history analysis. The building located in the town Hella was constructed in 1975, a year before the issue of the

first Icelandic earthquake code. Here the peak ground acceleration reached 0,47g in the earthquake of June 17.

The aim of the study was to compare the structural damages to results from such earthquake analysis. Furthermore, to propose structural remedial measure to the building.

Results from the earthquake analysis were fairly consistent with the actual damage. Furthermore, the results emphasized the importance of increasing the earthquake resistance of the building and thus improve its performance in future earthquakes.

In general the study showed that the building would have suffered less damage, if the standard reinforcement detailing of the Eurocodes had been available and applied in addition to considering symmetry in the layout of structural members. Furthermore, that with relatively simple measures the safety of an existing structure can be increased considerably.

### VERIFICATION OF OUT-OF-PLANE URMB FAILURE MECHANISMS THROUGH SCALE TESTING – ID 1217

*L. F. Restrepo-Velez, Solingral S.A., Colombia*

The paper is devoted to analyze and verify the mechanical behaviour of some of the most common out-of-plane failure mechanisms on unreinforced masonry buildings (URMB), through the execution of a series of static tests on 1:5 scaled specimens on dry-stone masonry, including a report on the tests, the description of the testing devices and the specimens, the discussion of the similitude requirements and the analysis of results and conclusions of the tests. The tests are oriented to the development of analytical models for the application of a procedure for the seismic risk assessment of URMB at urban or regional scale.

### SEISMIC RETROFITTING OF AN UNDER-DESIGNED RC STRUCTURE – ID 1297

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Tanganelli, Dipartimento di Costruzioni, Università di Firenze, Italy*

An extensive program for seismic assessment of strategic and relevant buildings, particularly focused on school buildings, has evidenced that many reinforced concrete structures realized in the Italian seismic regions between the 50's and the '70s are under-designed with respect to seismic loads and, very often, also with respect to static loads only. In the ambit of this program, the school building of Londa (Italy), built in 1974, represents a remarkable case. The structural organism of this building presents many seismic vulnerability sources, originated by design and construction errors, together with the problem of a low concrete strength. The seismic response of such structure has been analyzed in details in a companion paper both by means of nonlinear dynamic analysis and by means of pushover analysis. The results of the performed analyses have shown that the structure is significantly under-designed for seismic loads, and that it has problems even for static loads only, therefore it needs to be suitably retrofitted. The intervention of seismic retrofitting of the structure is based, first of all, on the elimination of all the main seismic vulnerability sources found and, subsequently, on the integration of the existing structure with a system of new reinforced concrete shear walls, intimately collaborating with it in order to absorb both the horizontal and the vertical loads. The solution with the shear walls has been adopted after having analyzed different solutions, based both on innovative intervention techniques with seismic isolators or dissipators, and on traditional intervention techniques, such as the reinforced concrete jacketing of the existing columns. The adopted solution proved itself to be the most efficient and economical in the present case. Moreover, differently than the interventions with seismic isolators or dissipators, it solves the problem of resistance to vertical loads, besides solving the problem of the seismic loads.

### DEVELOPING A MODEL FOR SEISMIC RISK ASSESSMENT (SRA) OF INTERCITY ROAD NETWORKS IN IRAN – ID 1341

*F. Yaghoobi Vayeghan, Transportation Research Institute (TRI), Iran (Islamic Republic Of)*
*M. Hosseini, IIEES, Iran (Islamic Republic Of)*
*M. Firoozi Nezamabadi, Islamic Azad University (IAU), Iran (Islamic Republic Of)*

In this paper, a basic model was developed to assess seismic risk of intercity road and highway networks for Iran. This country is located in the high seismic region. There are many definitions for Risk (R) presented by researchers. The authors used the main relation: H=R*V Where: H is Hazard and V is Vulnerability. If it was defined Re and Rr as existing risk and reduced risk, respectively, which can be written as: Re=He*Ve and Rr=Hr*Vr Where: He, Hr, Ve and Vr are, respectively, the existing hazard, the reduced hazard, the existing vulnerability and the reduced vulnerability. Hosseini (2005), the second author of the paper, suggested IHr and IVr, which are respectively the reduced hazard and the reduced vulnerability indices, defined by the following equations: Hr = He (1-IHr) and Vr = Ve (1-IVr) IHr = PHr * CHr and IVr = PVr* CVr Where: PHr is the potential of hazard reduction; PVr is the potential of vulnerability reduction; and CHr and CVr stand for Commitment to implementation or the enforcement of execution or application. So, risk reduction index (IRr) is related to hazard reduction index and vulnerability reduction index as follows: IRr = IHr + IVr - IHr* IVr The model proposed based on the above equation. In this model it is tried to consider the most important and effective engineering, economic, social, etc. parameters involved hazard and vulnerability. It is useful for Iran and countries like it which have a pour and weakness intercity road networks.

### FRAGILITY ASSESSMENT OF REINFORCED CONCRETE FRAMES DESIGNED FOR REGIONS OF MODERATE SEISMICITY – ID 1513

*O. C. Celik, Georgia Institute of Technology, United States*
*B. R. Ellingwood, Georgia Institute of Technology, United States*

In regions of low-to-moderate seismicity, reinforced concrete (RC) frame structures customarily have been designed with little or no consideration of their seismic resistance. For example, in the Central and Eastern United States (CEUS), such frames traditionally have been designed for the gravity load combination 1.4D+1.7L using detailing provisions of ACI Standard 318. Reinforcing details that are typical in this type of construction may lead to deficiencies in the seismic performance of gravity load designed (GLD) frames in the event of a moderate or severe earthquake. As part of the move toward performance-based seismic engineering, research is underway to develop reliability-based structural analysis models for predicting behavior and performance of GLD RC frames for a spectrum of possible seismic hazards and for developing seismic fragilities that can be used as a basis for risk-informed decision-making. These reliability-based prediction methods require accurate models of structural members and joints, as well as efficient nonlinear finite element methods for performing the simulations leading to seismic fragilities. This paper focuses on modeling shear and bond-slip behavior of the beam-column joints in GLD RC frames. A model based on the experimental determination of joint shear stress and strain was adopted. The joint panel constitutive parameters were defined to replicate the experimental joint shear stress-strain relationships, and the effect of bond-slip was taken into account. The modeling scheme was validated using full-scale experimental RC beam-column joint test series for four different beam-column joint representations. Based on the comparisons of the simulated force-drift responses with the experimental counterparts, a model is recommended for use in simulating the seismic response of GLD RC frames for fragility assessment. Comparisons of seismic behavior estimated from the proposed model to behavior predicted when joint shear and bond-slip are neglected show the importance of joint modeling in seismic fragility assessment.

### SEISMIC RISK EVALUATION OF RC BUILDINGS USING FUZZY SYNTHETIC EVALUATION – ID 1518

*S. Tesfamariam, University of Ottawa, Canada*
*M. Saatcioglu, University of Ottawa, Canada*

Newer buildings' resilience to seismic hazard is improving with the application of recent design codes and quality of construction. However, the vulnerability of existing buildings is apparent due to the older design codes, inherent area of weaknesses or change in the initial design parameters. Hence, there is need for a comprehensive plan to identify critical structures and carry out repair and upgrading. However, the impending challenge remains to be finding the necessary funding from a limited resource. In this paper, risk based evaluation technique is proposed to quantify the seismic assessment and rank the corresponding building accordingly. The seismic hazard, building vulnerability and consequence of failure are handled in hierarchical structures and the relative importance between each parameter is computed using the analytical hierarchic process. Uncertainty and vagueness in the input parameters are handled using fuzzy synthetic evaluation. Sensitivity analysis is carried out to highlight the relative importance of each input parameter. The procedure is presented with sample applications.

### EVALUATION OF STRENGTH AND DAMAGE INDEXES FOR BUILDINGS – ID 1534

*V. Sigmund, University of Osijek, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*
*P. Brana, University of Osijek, Faculty of Civil Engineering, Croatia (Local Name: Hrvatska)*

In order to evaluate and improve seismic capacity of existing buildings 'seismic safety evaluation' and 'retrofitting' are very important tasks. Engineers make these evaluations with different methods, from too simple to too sophisticated ones. The presented method combines experimental data and engineering knowledge for evaluation of the seismic safety factors and expected structural performance under strong events. It makes distinction between the structures with problems and those without problems and is a quick way to check the behavior of structures against expected seismic demands. The method could also be used for choice of the optimal strengthening method and for verification of the quality of performed strengthening works. Proposed methodology can be considered as a useful engineering tool to provide a base for the planning of measures of restoration and reinforcement and to check their success. It roughly covers three vulnerability assessment levels required in the EC8: general stability, strength capacity and lateral displacements capacity.

### ASSESSMENT OF SEISMIC INFLUENCES TO THE EXISTING BUILDINGS IN BISHKEK, KYRGYZSTAN – ID 1556

*K. Yrysmendi, Seismology, Kyrgyzstan*

This article studies the seismic influence to existing buildings. As it is known for estimation of the structure vulnerability it is usually necessary real information about exposed existing buildings by past heavy earthquakes. Existing data tells that the researching area during 1960-2004 was not exposed by close heavy earthquakes. Nevertheless the city territory was exposed by small earthquake effects constantly. Obviously this fact is natural condition of seismic situation on given area.

### STRUCTURAL SEISMIC RISK ASSESSMENT OF THE HISTORICAL ITALIAN TOWN OF LAINO CASTELLO – ID 1565

*M. Mezzina, DICAR, Italy*
*G. Uva, DICAR, Italy*
*I. Trulli, DICAR, Italy*
*F. Porco, DICAR, Italy*

The paper presents the results of a research project concerned with the structural safety, rehabilitation and re-use of the ancient town of Laino Castello (Northern Calabria - National Park of Pollino), which is presently completely abandoned. The environment is characterised by a severe seismic risk and large presence of masonry residential housing, endowed with a high degree of vulnerability. Besides, relevant slopes are observed, with a quasi-vertical urban structure and buildings very close to the cliffs. This peculiar urban configuration makes the town particularly weak with respect to superficial landslides and rock-falls and possible interaction with the seismic hazard. The project, aimed at the safety assessment of the site and its buildings (and, in perspective, at the structural and functional rehabilitation) has been carried out in cooperation with the municipal administration. The site has been used as a real laboratory for the empirical observation of mechanical phenomena, application of theoretical models and experimental in situ testing. In the first phase, the characterization of the urban context and masonry structures was faced, by acquiring knowledge about historical, typological, architectural and structural aspects, local constructive techniques. In order to systematically store and organize all the information and data, an Urban and Territorial Informative System was designed and implemented, which was also the basis for the implementation of multi-level vulnerability models and the construction of damage scenarios. This included the definition of a I level seismic vulnerability assessment, based on poor data, commonly available at the urban scale, and of a II level one, based instead on typological, observational and mechanical data. In both cases, specific forms and procedures for data retrieval were developed. The procedures have been applied on the buildings of Laino Castello, implemented in the GIS and elaborated, providing a description in terms of vulnerability, damage and scenario maps.

### DESIGN CRITERIA FOR THE SEISMIC RETROFIT OF REINFORCED CONCRETE (RC) FRAMES USING FIBER REINFORCED PLASTICS (FRP) – ID 1570

*A. Rasulo, Università degli Studi di Cassino, Italy*

The use of Fiber Reinforced Plastics (FRP) in seismic retrofit of existing reinforced concrete (RC) buildings is increasingly gaining consideration in scientific and technical community. Recent international documents provide a guidance to designers interested in the use of so far not codified materials, focusing on the main aspects the retrofit intervention requires at sectional and member level. Many gravity load designed RC frames generally present an unsatisfactory seismic response mainly due to a lack of global ductility. They are indeed conceived without consideration of capacity design principles, and therefore brittle failure mechanism are to be expected with the formation of plastic hinging in columns prior than in beams, and potential damage to beam-column joints. The FRP can be used in the retrofit in order to modify the strength hierarchy and thus achieve a better seismic response. The paper addresses the issue of what horizontal over-strength and behaviour factor have to be used when such retrofit philosophy is adopted. Relationship between lateral capacity, design force reduction factor, ductility level and overstrength have been investigated. The lateral capacity and the overstrength factor are estimated by means of inelastic static pushover as well as time-history collapse analysis for various frames representative of the gravity load only designed RC buildings present in European seismic prone areas.

### EVALUATION OF SEVERAL REHABILITATION METHODS FOR AN EXISTING STEEL BUILDING – ID 1577

*S. Maalek, University of Tehran, Iran (Islamic Republic Of)*
*P. Tehrani, University of Tehran, Iran (Islamic Republic Of)*

In this study, the effect of using several rehabilitation methods to improve the seismic performance of an existing 9 story steel structure has been investigated using nonlinear static and nonlinear dynamic analyses. These methods include the use of the EBF systems; RC Shear Walls and use of Passive energy dissipators such as metallic TADAS dampers, viscous dampers,

viscoelastic dampers and friction dampers. Each damping system has been modeled in the structure for several damping ratios and damper properties. In nonlinear dynamic procedure, the response of the structure to seven scaled earthquake records matched to the design spectrum has been obtained and the average value of the displacements, base shears, base moments and dissipated energies in structural members are used for comparison. The results demonstrate that using viscous and viscoelastic dampers for this structure can substantially reduce the potential of damage in structural members, particularly in columns. Because these kinds of dampers exert their maximum forces in out of phase with displacement most of the columns remain elastic.

### CUMULATIVE SEISMIC VULNERABILITY ASSESSMENT BASED ON THE CAPACITY-SPECTRUM METHOD – ID 1584

*N. Kyriakides, University of Sheffield, UK*
*K. Pilakoutas, University of Sheffield, UK*

In seismic vulnerability assessment the aim analytical procedures is to produce a damage index, which can then be related to the vulnerability of the structure. The most documented procedures for assessing the damage grade of RC buildings include,

• Assessment of the change in the dynamic parameters of the structure • Evaluation of the horizontal inter-story drift and global ductility or a combination of them. • Assessment of the residual strength capacity of the structure. • The Capacity Spectrum Method, which use of the relationship between displacement demand and capacity.

The first three methods have limitations such as they only deal with global effects and ignore the loading history. In this paper a procedure will be outlined and demonstrated in which the capacity-spectrum method is used to evaluate existing structures with strength degradation. The procedure is based on the equal ductility method, which is used to define the performance point (capacity curve meets demand spectra) for each PGA level. After the performance point is established, the loss of strength is evaluated along with the corresponding displacement ductility. A damage index is then estimated considering the effect on damage of both ductility and strength degradation by applying weighting factors according to the severity of the damage produced. It is assumed that displacements due to ductility cause only cracking and require fewer repairs, therefore smaller weighting factor is attributed for low ductility levels. Strength degradation is attributed greater significance and leads to higher vulnerability values. A third parameter used to obtain the final vulnerability of the structure is related to the damage potential. For example a structure that exhibited low ductility levels and no degradation after a particular event may still have high vulnerability depending on whether a slightly larger event would cause severe degradation or failure.

### URBAN BRIDGES VULNERABILITY STUDY IN MEXICO – ID 1607

*F. Espinoza, Universidad Autonoma de Baja California, Mexico*
*J. R. Juarez, Universidad Autonoma de Baja California, Mexico*
*E. Maldonado, Universidad Industrial de Santander, Colombia*
*C. Gomez, Universidad Autonoma Metropolitana, Mexico*
*J. P. Torres, Universidad Autonoma de Baja California, Mexico*

Ensenada, México, is a zone located to the south of Los Angeles, USA, affected by intense earthquakes. Therefore, a study of seismic vulnerability of the regional infrastructure is performed. This paper expects to contribute to the knowledge about security of structures and develop seismic risk maps.

Maldonado method is used to calculate the vulnerability index of urban bridges of Ensenada. That method uses 19 parameters that were determined with base in the studies realized on behavior seismic of bridges, experiences postearthquake, studies of existing models and opinions of experts.

The fuzzy mathematics are used to quantify the qualitative thing and in this work they are used to relate the qualifications of each parameter and its respective values of importance. The traditional method of combination of several pieces of information, with unequal importance or weights is used in this work to calculate the seismic vulnerability index of bridges.

### SEISMIC RISK ANALYSIS OF A CRITICAL FACILITY – ID 1610

*R. W. Romeo, Research Centre on Natural Hazards, Italy*
*Q. Napoleoni, Department of hydraulics, Italy*

Earthquakes are among natural hazards that threaten at most human activities. This is due to the polyvalent range of effects, spanning from direct damages related to the seismic shaking to indirect damages caused by collateral hazards such as fires, liquefaction, soils densification and landslides. The degree of vulnerability and the level of exposure of the threatened elements may further amplify such effects. In this sense, the seismic risk induced by an oil-gas storage plant located close to an important commercial harbour in Southern Italy is analysed. The plant is situated in one of the areas with the highest values of seismic hazard in Italy, affected by earthquake magnitudes as large as 7 in the past. Moreover, the plant lies near to the shoreline and the facing seafloor is characterized by the presence of a deep submarine canyon filled by loose, unconsolidated soils coming from the excavation of the harbour channel. On this bases the following phenomena have been investigated: local site amplification, liquefaction, submarine landslides and sea-waves run-up. The stability analyses regarded both the plant's structure itself and the site. A vulnerability analysis provided the response to the computed seismic actions of the steel tanks forming the structures, while dynamic analyses gave the response of the soils to the wide range of possible ground failures. Joining all the possible effects that could destabilize the plant, an overall risk measure that the stability and safety of the plant may fails was obtained. The total risk was then computed considering the effects, in terms of human life losses, produced by the failure of the plant and such risk was then compared with risks deriving from other human activities to provide a reasonable basis to consider it acceptable or not.

### SEISMIC BEHAVIOUR OF SQUARE R/C COLUMNS CONFINED WITH FRP – ID 2048

*C. Faella, Dept. of Civil Engineering - Univ. of Salerno, Italy*
*A. Napoli, Dept. of Civil Engineering - Univ. of Salerno, Italy*
*R. Realfonzo, Dept. of Civil Engineering - Univ. of Salerno, Italy*
*G. Rizzano, Dept. of Civil Engineering - Univ. of Salerno, Italy*

This paper focuses on the repairing and seismic retrofitting of existing reinforced concrete (R/C) "gravity load designed" (GLD) buildings. In particular, the preliminary results of a wide experimental program conducted to evaluate the seismic behaviour of R/C columns strengthened by using both carbon and glass fiber reinforced polymers (FRPs) are presented. The program - still in progress at the Laboratory of Structures of the University of Salerno (Italy) - consisted of monotonic and cyclic tests performed, under constant axial load condition, on full scale square and rectangular concrete columns, reinforced using both smooth and deformed steel rebars. Studied columns were realized to be representative of existing "GLD" building structural components, i.e. of structural elements designed with inadequate seismic details; for the same reason they have been produced with a low strength concrete. Tests were conducted on: a) columns strengthened by partially wrapping one or more carbon (CFRP) or glass (GFRP) fiber reinforced polymers sheets around the elements; b) columns retrofitted by using both the external CFRP confinement system and longitudinal steel angles placed at the corners of the concrete elements; c) unstrengthened columns – used as terms of comparison to evaluate the benefits of the abovementioned retrofitting techniques. The performed tests – carried out in displacement control - have allowed evaluating the improvements in terms of strength and ductility due to the external FRP wrapping. Furthermore, the analyses of the nonlinear cyclic behaviour of the tested columns have provided to draw useful information about the stiffness degradation and the energy dissipation phenomena. Finally, results in terms of rotation capacity were also compared with ones obtained applying the

formulations deriving from the technical literature and from new codes.

### A STUDY ON ECONOMIC SOUNDNESS OF SEISMIC RETROFITTING IN ITALY – ID 2057

*S. Santini, University of Roma Tre, Italy*
*C. Nuti, University of Roma Tre, Italy*
*I. Vanzi, University of Chieti, Italy*
*S. Sigismondo, University of Chieti, Italy*

Under which conditions is it economically convenient to seismic retrofit a structure? This paper presents both a procedure whose results allow to give a simple answer to the above question, central in earthquake engineering, and the results relative to the 8'100 municipalities in Italy. The procedure, already presented by the authors, uses as a starting point, the results of a standard reliability analysis conducted on the structure in its present state and after the retrofitting intervention. once these are known, expressed in terms of mean rate of exceedance of specified limit states, it is shown that it is possible to compute, via standard procedures of financial economics, whether the upgrading intervention should be made and how economically sound they are. This very procedure is then applied to the Italian territory: the hazard at the site of the Italian municipalities is first computed and then the economic soundness of retrofitting is discussed, with reference to the most frequently encountered structures, and with special emphasis on reinforced concrete ones, buildings and infrastructures. A simple and useful results is that, depending on the hazard, on the structural characteristics, on the consequences of collapse and on the retrofitting cost, seismic upgrading may or may not be economically sound. And plot of the results on the territory further clarifies where resources for seismic retrofitting, usually coming from public funds, ought better be employed.

### IN SITU EVALUATION OF STEEL STRESS IN R.C. MEMBERS WITH SMOOTH REBARS – ID 2072

*G. Fabbrocino, University of Molise, Italy*
*G. M. Verderame, University of Naples Federico II, Italy*
*M. Polese, University of Naples Federico II, Italy*

Structural assessment of existing reinforced concrete (R.C.) constructions results from a combination of experimental (determination of material properties and rebar detailing) and numerical evaluations (static and/or dynamic non linear analyses under design loads). In this framework, in situ estimation of reinforcement stress levels can give useful information about actual response of the structure under applied loads, but generally requires invasive and expensive operations. This paper presents an insight on the assessment of relationships between crack width and reinforcement stress in the critical regions of existing concrete buildings, such as column base or beam-column joints, reinforced with smooth rebars. The method is based on a numerical procedure that combines advanced modeling of the steel rebar for the computation of relationships between observed/monitored crack patterns and uncertainties affecting relevant structural parameters. Main numerical aspects of the deterministic approach to crack width estimation, validated against specific experimental results, are discussed. A regression analysis is then used to derive probabilistic estimation of the reinforcing steel stress.

## ES 9 & SS 5: Lessons from Recent Earthquakes

Level-1

### SEARCH AND RESCUE CAPABILITIES – ID 73

*A. K. Sinha, C.M.E, India*

Earthquakes are natural actions. These are bound to occur. Whatsoever precautions and measures are taken in constructing buildings, damage is expected during earthquakes. This underlines the need of sound rescue and relief preparedness to be in place for any seismic disaster mitigation scheme. Widespread damage during recent earthquakes in India as particular and round the globe in general, has substantiated this need.

Rescue works after a disaster are part of post-disaster emergency actions. These, in fact, form the most crucial phase of disaster mitigation programme. Proper coordination and increased efficiency shown in the first few hours of the disaster affects success rate more than such performances shown in any other phase of entire disaster preparedness programme. Number of casualties can be minimised with quicker evacuation of survivors entrapped inside collapsed buildings and providing them timely first-aid and medical attention. Yet, it gets the least attention in the overall disaster preparedness plan. Slackness replaces alertness due to uncertainty in occurrence of earthquake and in fact, long period between major earthquakes striking same region. The other factors have been traced out for identifying strength and weaknesses affecting success rate and efficiency of the immediate post-disaster operations.

There are several segments of society, which can form the rescue team. But, rescue and relief work after earthquake requires specific orientation and training to make the emergency work more effective. Author strongly feels that with short orientation for managing post-earthquake rescue and emergency rescue works will be carried out work more effectively. The various facets of rescue to enhance local SAR capabilities have been covered in this paper. Authors emphasize the development and enhancement of local Search and Rescue (SAR) capabilities to make this emergency action more effective.

### BOUMERDES ALGERIA EARTHQUAKE OF MAY 21, 2003: MAIN FEATURES AND BUILDING DAMAGE ANALYSIS – ID 192

*M. Belazougui, National Earthquake Engineering Centre (CGS), Algeria*
*M. N. Farsi, National Earthquake Engineering Centre (CGS), Algeria*
*A. Remas, National Earthquake Engineering Centre (CGS), Algeria*

The important earthquake of May 21, 2003, with 6.8 Magnitude that struck mainly the province of Boumerdes and the eastern part of Algiers province has resulted in very high toll of human losses (more than 2300 dead and 10000 injured people) and in very important damage to built environment (more than 100.000 dwellings or constructions collapsed or more or less seriously damaged).

In this paper, the main features of this major seismic event triggered by a previously unknown off shore fault will be briefly presented. Then, the building damage will be analyzed in terms of nature and degrees of damage to different categories of constructions in the different parts of the stricken region and the main weaknesses and insufficiencies of structures and the main causes of damage to the built environment will be underlined .

Finally the main lessons learned, up to now, from this very important event, will be presented in conclusion.

### INVESTIGATION ON THE SEISMIC BEHAVIOR OF SURFACE SOIL DURING THE 2003 BAM EARTHQUAKE IN IRAN – ID 250

*R. Motamed, The University of Tokyo, Japan*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*
*I. Towhata, The University of Tokyo, Japan*
*S. Tabatabaei, Building and Housing Research Center, Iran (Islamic Republic Of)*
*A. Shafiee, IIEES, Iran (Islamic Republic Of)*

The aim of this paper is to investigate the seismic behavior of surface soil, local site effect, during the 2003 Bam earthquake in Iran. Surface soil condition was studied as follows by three methods: microtremor measurements, Swedish weight sounding,

and SPT blow counts. Microtremor measurements were conducted at 49 sites in Bam city, and predominant period was estimated at each site by H/V method. Moreover, Swedish weight sounding test was performed at 4 sites, and average resonance period was calculated. Three boreholes were logged in Bam which one was located in the governor's office where accelerometer device recorded the main shock. Acceleration spectrum of the ground motion in the bed rock was back calculated by SHAKE analysis. Findings manifested that local soil did not amplify significantly ground motion. Furthermore, shear wave velocity in three boreholes were calculated using SPT values. Results from microtremor measurements and Swedish weight sounding, and SPT blow counts were compared to the seismic reflection survey which was carried out by IIEES. A good correlation was found, revealing that local soil have sufficiently good properties and can not be the main source for heavy damage to houses. In addition, damage survey was performed, and it was observed that damage intensity was high in the central part of Bam where houses were weak masonry and adobe structures.

## RELATION BETWEEN STRONG MOTION AND DAMAGE TO HOSPITALS IN THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE – ID 286

*M. Miyajima, Kanazawa University, Japan*
*A. Nebil, Kanazawa University, Japan*
*T. Ikemoto, Kanazawa University, Japan*
*J. I. Inagaki, Kanazawa University, Japan*

The present paper is focusing on the damage to hospitals in the 2004 Niigata-ken Chuetsu Earthquake. Health care facilities such as hospitals carry great importance principally following a disaster. The function of hospitals after an earthquake depends on many factors such as structural damage, lifeline damage, lack of staff, lack of medicine and others. Investigation of the relation between strong motion and damage to each component of a hospital during a large earthquake is necessary for evaluating the seismic performance of life saving facilities. Questionnaire survey was conducted for the hospitals suffering damage due to the 2004 Niigata-ken Chuetsu Earthquake. The relation between malfunction of the hospital and damage to each component such as structures, lifelines, instruments and so on was investigated. The relation between strong motion and damage to each component was also studies. Peak ground velocity (PGV) and JMA (Japan Meteorological Agency) seismic intensity were used as indices of strong motion in this study. Peak ground velocity at every 250m within the Niigata region was estimated by using a multi-asperity source-model, combined with a 7.5 arc-second Niigata-prefecture map of the average S-wave velocity of the upper 30m of the ground. The damage to each component of hospital is clearly related with simulated PGV rather than JMA seismic intensities. Simulated PGV is useful for estimating seismic performance of hospitals without JMA seismic intensity.

## MAGNITUDE DIFFERENCES OF ANDAMAN SEA EARTHQUAKES MEASURED IN SOUTHERN THAILAND – ID 514

*N. Setapong, Prince of Songkla University, Thailand*
*W. Lohawijarn, Prince of Songkla University, Thailand*
*H. Duerrast, Prince of Songkla University, Thailand*
*P. Nuannin, Prince of Songkla University, Thailand*
*P. Yongsiriwith, Songkhla Rajabhat University, Thailand*

After the Magnitude 9.3 earthquake off the West coast of Sumatra on 26 December 2004, the Geophysics Group, Prince of Songkla University, set up a temporary seismograph station at the Khao Chang telecommunication station in Phang Nga Province. The objective was to monitor earthquakes and aftershock events in the Andaman Sea area. Fifty-three events were recorded from 1 January to 12 January 2005 with body wave magnitudes ranging from Mb 4.5 to 6.6. The comparison of these magnitudes with the USGS earthquake catalogue data showed differences depending on the epicenter location. Earthquake events that were located in the area along and near the subduction zone, from the Andaman Islands in the North down to offshore Sumatra, the USGS magnitudes were about 0.3 higher than the values determined from the data recorded at the PSU station. For events East of the Andaman and Nicobar Islands the USGS magnitudes were only 0.03 higher. However, for events South of Nicobar Islands the USGS magnitudes were 0.2 smaller than those from the PSU station. These differences in the magnitudes might reflect differences in the travel pathways (e.g. different velocities) of the earthquake generated waves in relation to the point of measurement due to the complex geological structure of the subduction zone. For tsunami alert levels related to earthquake magnitudes determined by stations in Thailand these differences might have to taken into account. This work is still going on.

## SEISMICITY OF SOUTHERN THAILAND AFTER THE 26 DECEMBER 2004 ANDAMAN EARTHQUAKE – ID 520

*S. Dangmuan, Prince of Songkla University, Thailand*
*W. Lohawijarn, Prince of Songkla University, Thailand*
*H. Duerrast, Prince of Songkla University, Thailand*
*P. Nuannin, Prince of Songkla University, Thailand*
*P. Yongsiriwith, Songkhla Rajabhat University, Thailand*

After the magnitude 9.3 earthquake on 26 December 2004 off the West coast of Northern Sumatra, Indonesia, and the subsequent aftershocks questions emerged about the impact of this major earthquake on the fault zones in Southern Thailand, especially the Klong Mauri and Ranong Fault Zone. The Khlong Marui Fault Zone is well defined since early geological work as it marks clear boundaries on the topographic and geological map. The surface expression of the Ranong Fault Zone is less developed. However, both fault zones are well known from the hydrocarbon exploration in the Chumphon Basin, Gulf of Thailand on the east side and the Mergui Basin in the Andaman Sea on the west side of the Thai Peninsula. The Khlong Marui and Ranong Fault Zone are both NE-SW trending structures and shown on maps as strike slip faults with a possible sinistral motion.

Many people believed that these faults were dormant, although there was a magnitude 5.6 earthquake reported on 30 September 1978 along the Ranong Fault (Nutalaya, 1994). In early January 2005 the Geophysics Group of Prince of Songkla University installed a set of short period seismographs in the provinces of Phuket, Krabi, Pang Nga to monitor the seismicity of the Klong Marui Fault Zone. Over a period of six months, 162 earthquake-events were recorded in the area bounded by longitude 7.25 degree N to 10.12 degree N and latitude 97.26 degree E to 99.69 degree E. Several of these earthquakes are aligned parallel to the NE-SW trending fault zones, indicating that they are seismic active, at least in the aftermath of the 26 December 2004. The work is still going on.

Nutalaya, P., 1994. Assessment and mitigation of earthquakes: Selected areas of Southeast Asia. UN Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand: 205-260.

## BOUMERDES EARTHQUAKE PART I: CHARACTERISTICS OF THE EARTHQUAKE – ID 622

*H. Masanori, Waseda University, Japan*
*R. Kheir-Eddine, University of Science and Technology of Oran, Algeria*
*O. Yasuko, Kyoto University, Japan*
*M. Masakatsu, Kanazawa University, Japan*

On May 21, 2003 at 19:44:19 local time the Boumerdes earthquake struck the Zemmouri region in northern Algeria. Zemmouri is approximately 70 km east of the capital, Algiers. The moment magnitude of this event is 6.8 determined by U.S.G.S. The focal depth of the earthquake was about 10 km. The earthquake occurred in the boundary region between the Eurasion plate and the African plate.

This earthquake, which is the biggest to hit Algeria since 1980, killed 2278 people and injured more than 11,000 people. The large number of collapsed houses and public buildings was the direct cause of the loss of the human lives. Moreover, the earthquake disrupted health services, water supply lines, electricity, and communications in the region.

Japan Association of Earthquake Engineering (JAEE), Japan Society of Civil Engineering (JSCE), Architectural Institute of Japan (AIJ) and Japan Geotechnical Society (JGS) have cooperatively organized a reconnaissance team that was sent to investigate the damage inflicted by the Boumerdes Earthquake.

In part I, the geologic and tectonic settings of Algeria, the history of past earthquakes, and the characteristics of the recent earthquake are highlighted. Moreover, the liquefaction and geo-related failures investigated by the Japanese experts revealed.

### BOUMERDES EARTHQUAKE PART II: DAMAGE TO STRUCTURES – ID 633

*J. C. Vielma Pérez, Universidad Centroccidental Lisandro Alvarado/UPC, Spain*
*W. Lobo Quintero, Universidad de Los Andes, Venezuela*
*P. Rivero Rivero, Universidad de Los Andes, Venezuela*
*R. Kheir-Eddine, University of Science and Technology of Oran, Algeria*
*H. Masanori, Waseda University, Japan*
*S. Taiki, Building Research Institute, Japan*
*K. Kazuo, Tokyo University, Japan*
*M. Kimiro, Tokyo University, Japan*

As far as the seismic design code is concerned, the Algerian government adapted French practice of seismic design after the 1954 Orléansville (El-Asnam) earthquake disaster. This design practice did not consider properly the specific feature of strong earthquakes in Algeria. In 1978, a new guideline adapting the up-to-date knowledge of seismic design was proposed by the CGS (National Earthquake Engineering Center) with the assistance of Stanford University, U.S.A. This guideline was adopted in design practice after the occurrence of El-Asnam 1980 earthquake disaster. In 1999, the guideline was officially regulated as a law, RPA99, and was enacted in 2000.

The Boumerdes earthquake caused devastation. A large extent of structural damage was observed in the area near the epicenter including Zemmouri, Boumerdes and the suburbs of the capital Algiers. In Boumerdes City only, 7,400 concrete buildings were destroyed and 7,000 buildings were heavily damaged. Of approximately 96,974 buildings surveyed by the CGS most of the damage occurred to the residential buildings. Industrial building too suffered damages, and of the 25 bridges inspected, it was revealed, however, that no bridge stopped completely from operation and bridges that possessed anti-seismic steel elements did not suffer any damage.

Looking at the extend of the damage, one might question the reasons for such extensive destruction. Was it due to 1) severity of the ground motion? 2) Soil conditions which may have amplified the intensity of the ground shaking? 3) Shortcomings in building design code and/or construction method? 4) Or a combination of several factors?

In part II, structural damages are reported and the causes triggered with the aid of satellite imagery analysis and both the lamppost-support crack survey and the microtremor measurements, which have reflected local site effect.

### ATTENUATION OF INTENSITIES IN THE BALAKOT PAKISTAN EARTHQUAKE OF 2005, MW7.6; A FIELD OBSERVATION – ID 663

*M. Zare, IIEES, Iran (Islamic Republic Of)*

The Balakot earthquake of 8 October 2005 with a Mw7.6 caused a life loss of more than 73000 person based on the official reports. The reactivation of the Muzaffarabad fault (partially known as the Murry fault) caused the mainshock. This fault is parallel with the Main Boundary Thrust fault zone, in a NW-SE direction. The fault system is located in the Hazara syntax in the NE of Islamabad. The fault was traced on the surface according to the surface ruptures reported between Bagh and Balakot, along with a trend of a length of about 120km. The earthquake caused several surface coseismic ruptures in the epicentral region that interrupted the major roads and therefore major difficulties in the relief efforts. The landslides were of different types of debris slides, rock falls, and rock-block topples and slides. This paper is focused on the observed earthquake intensities in the fault normal and fault parallel directions. The events caused the greatest intensity of X-XI in the macroseismic epicenter (in Balakot). The intesities on EMS-98 scale are assessed based on structural damages and the geotechnical evidences. The intensity in the city of Muzaffarabad was observed to be IX, where it is estimated to be VIII in Balakot and Bagh. The event was felt in Islamabad with an intensity of VI. The attenuation rate was highest in the fault normal direction and the lowest in the fault parallel direction. Some few strong motion acceleration records are recorded in this event, the greatest one was obtained in Abottabad with a epicentral distance of about 55km and a maximum PGA of 0.21g. The attenuation of intensities are formulated by in a form of an empirical law. Such formalas have great importance in the reevaluation of seismic hazard maps in Pakistan.

### URBAN RECOVERY PROCESS FROM A DISASTER – ID 753

*K. Koshiyama, DRI, Japan*

Many disasters caused extensive damage to some cities in the world. In most cases many housings and public buildings had been rebuilt at same or distant locations, so physical environments and social conditions were changing and developing step by step. In the process the urban areas were transformed into new living spaces for survivors. The case of Hanshin-Awaji area attacked by the large earthquake in 1995 is valuable for learning lessons in considering a disaster recovery program. This study reported the transformation for ten years to examine the urban reconstruction program. First, we clarified characteristics of basic condition in damaged areas by gathering and analyzing of national population census in 1990, 1995, 2000 and public statistics of local governments. Second, we extracted distinctive blocks from damaged areas through urban whole recovery process by factor analysis of statistic data, and grasped the changing process of physical environments by geographic analysis of digital map data, aerial photographs and so on. Finally, we reviewed a series of recovery policies and showed the relationship between public planning and the urban transfiguration. We could have two main conclusions in this study. One it is important to make a disaster recovery plan for providing housings with due consideration for the effect on the urban transfiguration, especially of living environments, the other it is necessary to develop urban recovery methodology for a new safety city.

### DEVASTATIONS IN RECENT MASSIVE EARTHQUAKES : POSSIBLE COUNTERMEASURES – ID 789

*H. Tahghighi, Tokyo University, Japan*
*K. Konagai, Tokyo University, Japan*

In the last decades of the 20th century and the first few years of the 21st century, the loss of human lives in natural disasters was reported to be more than one million. Countless number of people had been left destitute and many communities suffered huge economic loss. Such terrible damages to life and property call for increased efforts in investigating causes of disasters, evaluating their risk and developing procedures for mitigating their effects. One of the important concerns is to discuss the possible measures for minimizing losses of life and damage to a variety of structures during the strong ground motions. This needs well organized technical committee to establish remedial measures for damage to structures. It was thus a natural must for this type of research activity to incorporate individual works of many others, especially with respect to risk identification and analysis.

The geotechnical aspects involve in natural disasters such as earthquakes, fault-inflicted damage, liquefactions and land slides are broad and complex experience-based discipline. Because of their nature, the field of geotechnical earthquake engineering associated with ground disasters is often regarded as a significant research topic. Until something disastrous happens, no problems have been identified or recognized as important for further studies. Learning from what has happened is the most important consideration and should never be missed. In fact, whenever serious damage has

occurred due to earthquakes, new horizons have been discovered and significant advances made in the development of geotechnical and structural engineering. For this, archiving available data in a systematic way will be quite necessary. This paper aims to give some hints for rational remedial or design measures for civil-structures and infrastructures whose constructions were/are unavoidable in geotechnical hazardous areas.

### THE BAM, IRAN EARTHQUAKE OF 26 DECEMBER 2003 WITH EMPHASIS ON STRONG GROUND MOTION RECORDS – ID 806

*A. A. Moinfar, Building and Housing Research Center, Iran (Islamic Republic Of)*
*A. Naderzadeh, Maharem Group, Iran (Islamic Republic Of)*

On 26 December 2003 an Mw6.5 earthquake strongly hit the city of Bam in southeast of Iran. The earthquake destroyed parts of the Bam city and the historic Bam Citadel. Over 32,000 people lost their lives due to this earthquake. The maximum intensity of the earthquake was IX (MMI) in a very limited area of the Bam city. The hypocenter was located within the city limits and about 7 km below surface. There were 78 strong motion instruments installed within a 300 km distance from the Bam city, among which over 25 instruments recorded the main shock of the earthquake. The most significant accelerograms were recorded in Bam. The Peak Ground Accelerations (PGAs) were 0.80g and 0.64g in the horizontal and 1.0g in the vertical directions. The Bam earthquake demonstrated some unique geological, seismological, and earthquake engineering features that can contribute to the present knowledge in these fields. This paper presents the strong motion characteristics of the earthquake such as the recorded PGAs, particularly the vertical peak acceleration of over 1.0g in an Mw6.5 earthquake that was recorded on the earthquake fault. Among other significant characteristics of this destructive event, the following aspects are also discussed in the paper: Rapid attenuation of the PGAs, release of the most of the energy in a short period of time, amplification feature of the under ground soil, near field effect, features of the intact buildings in the most destructive area. The discovery of the causative fault of the earthquake that was a hidden fault passing right under the Bam city was one of the most significant features of the Bam earthquake. This feature is also presented in details in the paper.

### CALIBRATION OF RAPID VISUAL SCREENING SCORES TO LOCAL STRUCTURES IN IRAN – ID 823

*F. Nateghi, IIEES, Iran (Islamic Republic Of)*

Rapid evaluations of existing structures in a built environment and quick assessment of disaster planning is an important task in earthquake prone regions. Many establishments have devised their evaluation forms and modifiers for assessment propose such as ATC. In this study due to unique opportunity after bam earthquake of iran, an attempt was done to calibrate the ATC scores based on local conditions. In this study, 384 buildings after the devastating Bam Earthquake were studied in details . Likely all kinds of structures such as masonry , R/C and steel buildings existed in this survey . based on ATC scores and investigated records, modifiers were calculate , therefore a set of modified structural scores were suggested. This paper will present the procedure and results obtained. Calibration technique will be also discussed.

### DYNAMIC BEHAVIOUR OF RC BUILDINGS AFFECTED BY THE 2004 AL HOCEIMA (MOROCCO) EARTHQUAKE USING AMBIENT VIBRATION MEASUREMENTS – ID 928

*F. Vidal, Granada University, Spain*
*M. Navarro, Almería University, Spain*
*T. Enomoto, Kanagawa University, Japan*
*E. Ocaña, Granada University, Spain*
*T. Mourabit, Abdelmalek Essaadi University, Morocco*

The natural period and the damping factor of buildings are important parameters to determine the dynamic behaviour of building structures during seismic shaking and have been used to estimate potential damage of buildings during future earthquakes. The analysis of ambient vibration measurements is a quick, easy and inexpensive way to estimate the natural period of buildings. The February 24th, 2004, Al Hoceima (Morocco) earthquake (Mw 6.4) reach an intensity degree of VIII(EMS) over an area among Ait Kamral, Aït Kamral, Ajdir, Tazârhîne and Imzoûrene, where an intensity of VIII-IX was observed locally. Most of the severe structural damage including collapse occurred in adobe and rubble masonry constructions but, unfortunately, around fifty reinforced concrete RC buildings suffered also collapse in Imzoûrene and more than one hundred with severe structural damage in Ajdir and Imzoûrene. Ambient vibration measurements were performed in Imzoûrene and Al Hoceima cities at the top of a set of RC buildings (from 2 to 5 stories) using a three component seismometer. Fourier spectra were computed from every record in the longitudinal and transversal components. The relationship between the oscillation period of the swaying motion and the story number of undamaged (and for damaged also) RC buildings has been estimated and the damping factor using the Random Decrement Technique, in the small amplitude region, was calculated. Results show that the natural periods for undamaged RC buildings are slightly longer than those obtained in several cities of the South of Spain. The relationships obtained for damaged buildings are strongly dependent of the severity of the damage.

### EFFECTS OF LOCAL SITE CONDITIONS ON BUILDING DAMAGE DURING THE ZARAND (FEB2006, IRAN) EARTHQUAKE – ID 1283

*A. Kavand, University of Tehran, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*

A damaging earthquake struck the southeastern part of Iran (Zarand) on February 22, 2005. A great number of buildings were severely damaged or collapsed during the earthquake. Adobe buildings were completely collapsed or suffered heavy damage. Un-reinforced masonry buildings (URM) were damaged because of absence of tie beams and poor construction quality. Some masonry buildings with pre-cast concrete roof slabs were damaged located up to 5 kilometer far from the epicenter. In order to examine the possible effects of local soil conditions (site effect) on ground motion and distribution of earthquake damage, some microtremor measurements were conducted on ground surface in several locations in the affected area. Also microtremor measurements were conducted on top of some survived adobe and masonry buildings in order to obtain their seismic response characteristics. The results show good relation between ground microtremor findings and the dynamic characteristics of buildings which collapsed in many places but survived in some parts of the affected area.

### SOME SPECIFIC LESSONS FROM THE MONTENEGRO 1979 EARTHQUAKE RELATED TO SEISMIC HAZARD AND DAMAGE ASSESSMENT – ID 1311

*B. Pavicevic, Civil Engineering Faculty, Yugoslavia*
*B. Glavatovic, Montenegro Seismological Observatory, Yugoslavia*
*J. Mihaljevic, Montenegro Seismological Observatory, Yugoslavia*

The experience accomplished after the destructive 1979 Montenegro earthquake, magnitude 7.0, has the lasting significance, not only in former Yugoslavia, but also in larger international community. The special attention in this paper is devoted to the methodology of post-earthquake urgent measures, particularly to the inspections and damage classification of more than 64.000 buildings and lifeline systems as well.

Regarding current activities on the revision of the Physical development plan of Montenegro an effort was made to reaffirm particular experience in seismic risk reduction after disastrous Montenegro earthquake, gained through the UNDP-YUG/79/104 Project. This

project was realized in a unique methodological approach of integrated and comprehensive planning based on the extensive evaluation of the damages caused to urban and rural settlements, historical and cultural heritage to infrastructure and the production activities especially to the tourism and industry. The main components of the project (besides of the statement on integrated approach to the development planning) were seismic risk reduction and environment protection; results, approaches and concepts developed through it should be pointed out.

The seismic monitoring capacity in Montenegro was highly improved at the end of 1982, by installing a telemetry seismic network with 10 stations. It provides the valuable basis for much better seismic hazard assessment in the region. The current seismic monitoring tools make possible near real time dissemination of earthquake parameters. Also, the evaluation of probable earthquake intensity distribution according to a set of macroseismic models, can serve for the urgent estimation of possible earthquake effects.

The current activities on the revision of the Physical development plan of the Montenegro, including preparation and strengthening of institutional and legislative system, as well as its harmonization with EU regulations, represent the opportunity for the establishment of the adequate strategy for the integrated national strategy for seismic risk management.

## CONSEQUENCES OF "LUGOVSKOYE" EARTHQUAKE – ID 1362

*T. Anvar, KazNIISSA, Kazakhstan*

The earthquake of May 23, 2003 in Republic of Kazakhstan on the data of "Almaty seismic station" had magnetude 5,4 and depth of the focus from 4 up to 8 km. The earthquake intensity displayed varied grades within limits from 7 up to 8 in the epicenter in conformance with MSK-64 scale. The earthquake has caused significant and moderate damages to structures in territory by the area more than 100 square km. Not serious damages done to structures were observed on the area about 500 square km. In a zone, most severely damaged by the earthquake, there were seven settlements populated by about 30 000 people. As a result of earthquake 3 men were lost, some tens have received wounds. All lost were children of school and preschool age. The economic loss caused by the seismic event, has exceeded US $120 mln. As a result, during the earthquake practically all detached residential buildings made from adobe, slag stones and bricks which has appeared in a zone affected by the quake with intensity from 7 up to 8 grades, have received damages of 2 and 3 degrees, and some adobe hoses - 4 and 5 degrees. It's evident that approaches relevant to designing of objects for construction in towns and villages in standard documents regulating rules of construction in seismic areas should be differentiated. Moreover it's expedient to enhance requirements to buildings which exploitation is connected with large quantity of children gathering i.e. schools, kindergartens, play-schools, health-care institutions. In particular, it is recommended to assume the above mentioned buildings with restricted height of no more than 2 floors and design seismic loads should be assumed with heightening coefficient of 1,3-1,5.

## STRONG EARTHQUAKES IN THE PERIOD OF 1991-2001 AND THE CONSEQUENCES INFLICTED TO URBAN AREAS – ID 1382

*K. Talaganov, Institute of Earthquake Engineering, Macedonia*
*V. Sesov, Institute of Earthquake Engineering, Macedonia*
*I. Zafirova, Institute of Earthquake Engineering, Macedonia*
*V. Gadza, Institute of Earthquake Engineering, Macedonia*

The characteristics and the consequences of strong earthquakes that have taken place in urban areas for the period of 1991-2001 have been the subject of research. Out of the total number of damaging earthquakes that have occurred throughout the world, only about ten percent have occurred in the near vicinity of urban regions. Considering the increasing technical-technological growth in the world, the increased number of population and the extensive urbanization, this percentage is expected to rise in future. The earthquakes have caused heavy material damage and loss of human lives resulting from heavy damage and failure of structures. The reasons for this have extensively been known but have been confirmed and stressed out by these earthquakes. However, these events have also led to new knowledge about the effects of near field strong earthquakes and the strong influence of the local soil media upon the earthquake effect. It has been concluded that the heavy consequences have mainly been due to disrespect of modern principles of construction. Although there is still a need for more extensive research in earthquake engineering field, strenuous efforts are still to be put by the wider social community toward mitigation of seismic risk as an important and urgent imperative. Since it is difficult to eliminate seismic risk completely, the wider community should be much better prepared to take obligations, preventively finance the mitigation of the seismic risk and efficiently respond to earthquakes once they occur.

## THE IRISH SEA EARTHQUAKE OF DECEMBER 14 2005 – ID 1385

*T. Blake, Dublin Institute for Advanced Studies, Ireland*

The DIAS regional seismic network began recording events from 1978. The largest local/regional event it has registered was an event in north Wales with a 5.4Ml magnitude in July 1984. The event on December 14 in the Irish Sea area occurred at 03:30am and initial estimates suggest 2.8Ml magnitude. This region is more seismically active relative to the remainder of the country. The relationship between this event, along with previous ones and the regional geology will be explored and examined. Evidence from the gravity data for the region will also be examined to support the structural geology. The implications of this event for the argument for a state funded national seismic network will be discussed.

## DAMAGE IN NIAS ISLAND CAUSED BY THE M8.7 OFF-SHORE SUMATRA EARTHQUAKE, MARCH 28, 2005 – ID 1426

*S. Miwa, Tobishima Corporation, Japan*
*O. Aydan, Tokai University, Japan*
*H. Kodama, Tobishima Corporation, Japan*
*J. Kiyono, Kyoto University, Japan*
*I. Endo, Taisei Kiso Sekkei Co., Ltd., Japan*
*T. Suzuki, Tobishima Corporation, Indonesia*
*M. Hamada, Waseda University, Japan*

A very large earthquake with a magnitude of 8.7 occurred nearby Nias Island of Indonesia on March 28, 2005. Although the magnitude of the earthqukae was large, the scale of the induced tsunami was very small. This may be due to the particular sea topography and small amplitude of the uplift of the seabed. Strong ground motions induced heaviy casualities and damages to structures. Although the magnitude of the earthquake was much smaller than that of December 26, 2004, the induced strong ground motions were much higher. The earthquake induced widespread liquefaction and lateral spreading. These phenomena were the primary cause of heavy damage to bridges and buildings in Nias Island. RC buildings are generally found in cities and towns. RC buildings having 2 or more stories were cllapsed or heavily damaged in the pancake mode. The main causes of the damage of the structures in this earthquake can be broadly classified as follows: a) Soil liquefaction and lack of the soil bearing capacity in the coastal areas and nearby river banks, b) Fragile structural walls and lack of lateral stiffness. c) Poor concrete quality and workmanship d) Plastic hinge development at the beam-column joints, e) Lack of shear reinforcement and confinement, f) Soft story, g) Ground motion characteristics and so on. As expected from the magnitude of this earthquake, the liquefaction of sandy ground is very likely. Lateral ground movements, settlement and the effects of ground liquefaction such as sandboils were observed at the sandy ground along sea shore and riverbanks. Many buildings collapsed, tilted and settled, also bridges and port facilities were damaged along the castal area and reclaimed ground in Gunung Sitoli, Teluk Dalam and other lowland area. The lateral spreading of ground nearby bridge abutments were almost associated with liquefaction of sand soil layer.

### HOUSING RECONSTRUCTION PROCESS OF THE GREAT HANSHIN-AWAJI EARTHQUAKE DISASTER – ID 1554

*K. Koshiyama, DRI, Japan*

Many disasters caused extensive damage to some cities in the world. In most cases many housings and public buildings had been rebuilt at same or distant locations, so physical environments and social conditions were changing and developing step by step. In the process the urban areas were transformed into new living spaces for survivors. The case of Hanshin-Awaji area attacked by the large earthquake in 1995 is valuable for learning lessons in considering a disaster recovery program. This study reported the transformation for ten years to examine the urban reconstruction program. First, we clarified characteristics of basic condition in damaged areas by gathering and analyzing of national population census in 1990, 1995, 2000 and public statistics of local governments. Second, we extracted distinctive blocks from damaged areas through urban whole recovery process by factor analysis of statistic data, and grasped the changing process of physical environments by geographic analysis of digital map data, aerial photographs and so on. Finally, we reviewed a series of recovery policies and showed the relationship between public planning and the urban transfiguration. We could have two main conclusions in this study. One it is important to make a disaster recovery plan for providing housings with due consideration for the effect on the urban transfiguration, especially of living environments, the other it is necessary to develop urban recovery methodology for a new safety city.

### AN INVESTIGATION INTO OPERATIONAL CAPACITY OF SPECIAL STRUCTURES FOR CRISIS MANAGEMENT AFTER THE DECEMBER 26, 2003 BAM EARTHQUAKE – ID 1558

*H. Afshin, Sahand University of Technology, Iran (Islamic Republic Of)*

A powerful earthquake occurred in Bam city, south-east of Iran on 26 December 2003. About 70% of the city buildings were destroyed. The majority of the crucial essential buildings for crisis management such as hospitals, fire stations, telecommunications centers, governor office, and aid-supplying depots were so heavily damaged that could not be applied in the rescue operations. In this study the structural behavior of these buildings and its effects on their operational capacity after earthquake are investigated. The seismic performance of these buildings is discussed and their strength and weakness points are highlighted. Based on the results of this field investigation, it can be concluded that inaccurate detailing, use of weak materials, thick roofs (for thermal insulating in hot weather of region), lack of suitable lateral-load-bearing systems (due to absence of experience of strong earthquake in the past 2000 years in region), weakness of joints between structural elements, irregular plan, poor workmanship and etc. were reasons for damages to many of these buildings. This research is an attempt to provide an opportunity to raise awareness of the importance of seismic safety of crisis management special buildings for post-earthquake rescue operations and highlights the necessity of seismic retrofitting of these buildings for risk reduction in Iran as well as in other hazard-prone countries.

### THE 21ST OF MAY 2003 EARTHQUAKE EFFECTS ON THE ENVIRONMENT OF ALGIERS – ID 1560

*A. Zerzour, Civil Engineering Faculty- Algiers University, Algeria*
*H. Zelloum, Civil Engineering Faculty- Algiers University, Algeria*
*M. Chabaat, Civil Engineering Faculty- Algiers University, Algeria*

An earthquake of a magnitude Ms= 6.6 (according to CSEM) and Ms=6.7 (after NEIC) on Richter Scale hit the city of Boumerdes and its surroundings on May 21st 2003 at exactly 19:44 pm. Boumerdes city is located on coast line approximately 50 km from Algiers, Capital of Algeria. According to Harvard Center, the deformation at the level of the hypocenter is a reverse fault (direction NE – SW). On the basis of the seismic movement, the fault has the length of 15 to 20 km and a displacement of the order of 1 meter. Then, the hypocenter is considered as being superficial (approximately 10km). The epicenter zone is in the area of Boumerdes which is located at approximately 50km from Algiers. All the above information of earthquake has been reported by the Research Center of Astronomy, Astrophysics and Geophysics (CRAAG- ALGERIA). During the earthquake, 2300 human lives are lost, 9000 persons are injured and more than 3000 disappeared. One the other side, the damage of rural houses are estimated to be: among 10, 000 structures or rural houses visited just after the earthquake's hit, one noticed that 3500 are classified as requiring slight repair (70%) and some others presenting no damaging (30%). Besides, 3800 are classified as requiring a deeper evaluation of repairing and strengthening (36%) and finally, 3000 completely classified damaged and should be demolished (50%).

Key Words: Earthquake, Algeria, Fault, damage evaluation, Strong motion records, seismic intensity, accelerograms, magnitude estimation, isoseismal map, Disaster management, seismic risk.

### LESSONS FROM BAM EARTHQUAKE: SEISMIC BEHAVIOUR OF BUILDING STRUCTURES DURING THE EARTHQUAKE – ID 1587

*A. R. Manafpour, Halcrow Group Limited, UK*

The Bam earthquake on 26 December 2003 with magnitude Mw=6.6 destroyed most of the city of Bam in Iran and nearby villages, and killed more than 26,000 people. The earthquake was by far the most devastating earthquake in the history of the region around Bam. After the earthquake the author undertook a field investigation and visited the affected area. The paper studies the structural damage on traditional as well as modern building structures during the earthquake. The dramatic scale of the casualties associated with a relatively small affected region highlighted the particular vulnerability of other cities in the earthquake region.

The paper considers different types of the buildings in the earthquake affected area including: Adobe, masonry, steel and reinforced concrete structures with some examples demonstrating the response of each type of the buildings. Discussion of the structural behaviour is given with reference to existing seismic design codes and construction practice within the region. It is concluded that as a considerable number of buildings in central and eastern provinces of Iran, more specifically in villages, are built of mud-bricks and will not resist similar magnitude earthquakes. Due to specific materials and construction forms special strengthening procedures needs to be developed. A good majority of the non-traditional buildings are built of masonry or a combination of masonry and steel without any specific seismic considerations and are vulnerable to earthquakes. An active retrofit and renewal strategy should be formulated to encourage the owners to undertake retrofitting.

### GROUND MOTION CHARACTERIZATION IN THE MURCIA REGION (SE SPAIN) – ID 1759

*J. M. Gaspar-Escribano, Universidad Politécnica de Madrid, Spain*
*B. Benito, Universidad Politécnica de Madrid, Spain*
*J. García-Mayordomo, Universidad Politécnica de Madrid, Spain*

After fifty years of minor seismic activity, the Region of Murcia has been the focus of the three last significant earthquake series in Spain: the 1999 Mula, 2002 SW Bullas and 2005 La Paca series. These have been the last damaging earthquakes in Spain, reaching maximum intensities of VI and VII and causing significant economical losses but fortunately no casualties. Several factors contributed to the observed damage: buildings characteristics, local site effects due to the presence of soft soil and the severity of the seismic shaking. In this work we analyse the significance of ground motions. Ground-motion records correspond to large epicentral distances so they cannot be used to assess ground motion effects at damaged sites. However, the normalised spectral shapes are compared to the design spectral shapes used to construct the Spanish Building Code (NCSE-02). A systematic exceedance of

NCSE-02 spectral shapes by recorded spectral shapes for short periods is observed. This is corroborated in the epicentral areas where modelled spectral shapes also exceed their NCSE-02 partners for short periods. Implications of this result on seismic hazard in the Region are analysed. We show that the uniform hazard spectra for the 475-year return period can be decomposed into two response spectra, corresponding to short- and long-period spectral accelerations. The most significant hazard contribution comes from the short-period component. Hazard deaggregation shows that the larger hazard contributions correspond to moderate events originated at local sources. The corresponding specific response spectra are very similar to the uniform hazard spectra and exceed the corresponding NCSE-02 response spectra for short periods. We conclude that the response spectra specified in the NCSE-02 Code for the return period of 475 years may need to be revised in future versions of the code.

### A RESEARCH ON THE EVALUATION OF UNDERLYING RISK FACTORS IN THE AREA – ID 1788

*T. Shigaki, osaka city university, Japan*
*E. Ikuta, osaka city university, Japan*
*M. Miyano, osaka city university, Japan*

The 1995 Hyogo-ken Nanbu Earthquake (an inland earthquake) was the falling plumb down of the large metropolitan area, and made enormous damage in Kobe area, in Japan. In the physical damage, the complete collapse building exceeded 100,000 and 5502 persons were killed directly by this earthquake. That was the biggest sacrifice after the World War II;in Japan. Approximately above the half of victims, especially the dead person was the elderly over 65 years old and it showed the same tendency as natural disasters in the past. On the other side, the daily disaster which occurs in the everyday life exists in our life environment in addition to the natural disaster to attack us suddenly as earthquakes. There are many accidents in dwellings those belong to the daily disaster, and according to such accidents over 10,000 persons lost their lives every year. An overwhelming majority of the casualty due to the daily disaster is also the elderly over 65 years old. Such tendency is in common with the natural disasters. It is pointed out that the unexpected accident which represents a daily disaster occurs in relation to the attribute of people and buildings in the area. In aged society, Japan, it is very important to be clarified the influence of the elderly people ratio to underlying risk in the area. In this research, we grasped the status of the daily disaster in the primary and the junior high school unit which is the base unit of the insurance human services by the public administration in Osaka, at first. Secondary, we analyzed the relationship between the regional characteristics and the investigation results at first step. Lastly, we could clarify underlying risk factors in the area according to the evaluation above mentioned.

### FRAMEWORK OF BIOMECHANICAL MODELING FOR EVALUATING HUMAN BODY DAMAGES CAUSED BY COLLAPSED BUILDINGS IN GREAT EARTHQUAKE – ID 1815

*E. Ikuta, Osaka City University, Japan*
*M. Miyano, Osaka City University, Japan*
*F. Nagashima, Tokyo Metropolitan University, Japan*
*J. Ozaki, Tokyo Metropolitan University, Japan*

The 1995 Kobe Earthquake struck the southern part of Hyogo prefecture catastrophically and brought 5,502 immediate victims (not included the related death) and 10,683 serious injured. This number of casualties is the greatest in recent disasters in Japan. According to our comprehensive database about cause of casualty and building damage in the Kobe earthquake, it was found that the typical direct cause of death was suffocation due to thoracic compression, while the most of serious injured persons had a bone fracture at the region of abdomen, lumbar and thigh. This paper presents a framework of biomechanical modeling and evaluation method for impact and compression damages of human bodies caused by collapsed buildings in great earthquake. The final goal of this research is to provide high-precision virtual dummy for disaster mitigation by making use of the most advanced knowledge such as biomechanics and kinesiology. First, anatomy geometric shape data (CAD data) are converted into FE model data by translating through the intermediate EXCEL data. Model meshing and element forming are carried out. At this time, minute elements are eliminated for reducing CPU requirement. At next phase, bone crashing/bending simulation test and muscle compression test are conducted for finding physical properties of each element. As a typical cause of death, thoracic compression processes is simulated and the results is compared with CT-scanner experimental results. For a case of serious injury, we examine load carrying capacity of the muscle at the thigh region by both experimental and analytical study. Using the thigh model, damages under some cases of overturned furniture (type, material, shape of impact face) are investigated. Consequently, we establish a framework of biomechanical modeling procedure and evaluation method for human damage. The results of this study are available not only for safety evaluation but also for education on residents.

### THE ZAKYNTHOS (W. GREECE) SEQUENCE OF OCTOBER 2005 - APRIL 2006 – ID 1906

*C. Papaioannou, ITSAK, Greece*

A sequence of moderate magnitude earthquakes occurred south of Zakynthos Island (W. Greece) in April 2006 with magnitude of the strongest earthquake Mw5.7. An earthquake with magnitude Mw5.6 occurred at the same area on October 2005. In the present paper the space time distribution of the earthquakes for the period October 2005-April 2006 are presented. It is shown that within one month after the October 18, 2005 earthquake the seismicity rate was at the level of the background seismicity and on April 3, 2006 another sequence started at the same with the same type of faulting. All the available fault plane solutions show that the strongest of the earthquakes are associated with a low angle thrust fault with NW-SE direction. The earthquakes were strongly felt at the town of Zakynthos where minor damage were observed mainly to brittle structures. ITSAK operates at this area a strong motion array. The maximum recorded PGA was 22%g. The results of the strong motion data recorded at the broader area of Zakynthos Island are shown and discussed.

### SEISMICITY OF SOUTHERN THAILAND AFTER THE 26 DECEMBER 2004 ANDAMAN SUMATRA EARTHQUAKE – ID 1922

*S. Dangmuan, Prince of Songkla University, Thailand*
*W. Lohawijarn, Prince of Songkla University, Thailand*
*H. Duerrast, Prince of Songkla University, Thailand*
*P. Nuannin, Prince of Songkla University, Thailand*
*P. Yongsiriwith, Songkhla Rajabhat Institute University, Thailand*

After the magnitude 9.3 Andaman Sumatra Earthquake on 26 December 2004 and the subsequent aftershocks questions emerged about the impact of this major earthquake on fault zones in Southern Thailand, especially Klong Mauri (KMF) and Ranong Fault Zone (RFZ). In January 2005 the Geophysics Group installed short period seismographs in the provinces of Phuket, Krabi, PhangNga to monitor the seismicity. Over a period of about six months 157 earthquakes with Ml $<$ 2.5 were recorded in an area between longitude 7.25 N to 10.12 N and latitude 97.26 E to 99.69 E. Several of these earthquakes are aligned parallel to the NE-SW trending fault zones, KMF and RFZ, indicating that they were seismically active; others occurred in clusters. Before the 26 Dec 2004 earthquake the subduction zone in the Andaman area was locked and subsequently the Eurasian Plate with Thailand was moving towards East. The major earthquake unlocked this part of the subduction zone and lead to crustal deformation. This resulted to a westwards movement of the general Eurasian Plate in this region, documented by GPS measurements (Vigny et al, 2005). However, the greater area around Phuket and PhangNga showed significantly higher movement rates to the West than areas further North or South. A possible explanation is that the existing faults in the Thai peninsula were activated by the crustal deformation of the

26 Dec 2004 earthquake resulting in a differential movement towards the West. Further, the crust in the area in between the activated faults experienced extensional forces through this differential movement, resulting in cluster like earthquake occurrences.

Vigny, C., Simons, W.J.F., Abu. S., Bamphenyu, R., Satirapod, C., Hoosakul, N., Subarya, C., Socquet, A., Omar, K., Abidin, H.Z. and Ambrosius, A.A.C., 2005 Insight into the 2004 Sumatra-Andaman earthquake from GPS measurements in Southeast Asia. Nature, Vol. 436, 201-206.

### DEVASTATIONS IN RECENT MASSIVE EARTHQUAKES - POSSIBLE COUNTERMEASURES – ID 1978

*H. Tahghighi, University of Tokyo, Japan*
*K. Konagai, University of Tokyo, Japan*

In the last decades of the 20th century and the first few years of the 21st century, the loss of human lives in natural disasters was reported to be more than one million. Countless number of people had been left destitute and many communities suffered huge economic loss. Such terrible damages to life and property call for increased efforts in investigating causes of disasters, evaluating their risk and developing procedures for mitigating their effects. One of the important concerns is to discuss the possible measures for minimizing losses of life and damage to a variety of structures during the strong ground motions. This needs well organized technical committee to establish remedial measures for damage to structures. It was thus a natural must for this type of research activity to incorporate individual works of many others, especially with respect to risk identification and analysis.

The geotechnical aspects involve in natural disasters such as earthquakes, fault-inflicted damage, liquefactions and land slides are broad and complex experience-based discipline. Because of their nature, the field of geotechnical earthquake engineering associated with ground disasters is often regarded as a significant research topic. Until something disastrous happens, no problems have been identified or recognized as important for further studies. Learning from what has happened is the most important consideration and should never be missed. In fact, whenever serious damage has occurred due to earthquakes, new horizons have been discovered and significant advances made in the development of geotechnical and structural engineering. For this, archiving available data in a systematic way will be quite necessary. This paper aims to give some hints for rational remedial or design measures for civil-structures and infrastructures whose constructions were/are unavoidable in geotechnical hazardous areas.

## ES 10: Other Issues

Level-1

### CONTRIBUTION TO EVALUATION OF TECHNICAL SEISMICITY EFFECT ON BUILDINGS - CASE STUDY – ID 319

*M. Lednicka, VSB - Technical University of Ostrava, Czech Republic*
*B. Lunackova, VSB-Technical University of Ostrava, Czech Republic*
*E. Hrubesova, VSB-Technical University of Ostrava, Czech Republic*
*Z. Kalab, Institute of Geonics, Czech Republic*
*R. Korinek, VSB-Technical University of Ostrava, Czech Republic*

Study of seismic load on buildings and structures caused by technical seismicity has intensified due to increase of this load. This load is pursued not only for present structures but it must be checked as an entire part of project documentation for new significant buildings or for building proposed for reconstruction. Czech technical standards present structure classification on the basis of their response on seismic loading. Both socio-economic viewpoints and resistivity of studied structures are taking into account. Proposal for use of this classification for detailed studies in regions with significant loads by technical vibrations is presented in this contribution. Ostrava and Karviná regions were selected as study areas. The main reason is synchronous occurrence of different types of technical seismicity - mining induced seismicity, traffic vibrations, industrial activity effects, etc.). Another task is to select suitable structures for experimental measurement in this model area. Individual buildings require different approach for evaluation of their seismic load according to present Czech technical standards. Buildings and structures with the most rigorous criteria for judging the seismic loading will be the most suitable to select for initial studies. Sufficiency of discussed buildings and structures is available for experimental measurements in the study area. Amount of places for experimental measurements will decrease after confrontation with the information about current occurrence of seismic loads caused by technical seismicity of a certain type in this area. Maps of clashes of opinions, which should help to choose the measurement area and suitable structures, will be the result of this evaluation.

### AN APPLICATION OF ARTIFICIAL NEURAL NETWORKS FOR RELIABILITY ANALYSIS AND PERFORMANCE BASED DESIGN – ID 758

*H. Ghalibafian, The University of British Columbia, Canada*
*R. Foschi, The University of British Columbia, Canada*
*C. Ventura, The University of British Columbia, Canada*

Reliability estimates and performance-based optimization in earthquake engineering requires the calculation of structural responses as functions of the intervening random variables, including those defined as design parameters. Since the calculation of the responses implies the application of nonlinear dynamic analyses, integration of such routines within reliability methods, like simulation, results in heavy computational demands. The process is made very efficient by an a-priori representation of the responses via response surfaces or artificial neural networks. Although the development of databases for the training of such networks still requires a substantial computational effort, the a-posteriori use of the networks in simulations becomes very efficient and permits a fast calculation of reliability levels, by themselves or as part of an optimization for performance with specified reliabilities. The input to the neural networks includes the structural variables and, in the case of soil-structure interaction, also those associated with the soil properties. The variables corresponding to the ground motion can be treated individually (peak intensity, duration, random phases associated with the frequency content of the signal). Alternatively, the grouped effect of these variables, or different selected earthquakes, can be calculated for specific choices of the structural and/or soil variables. The statistics corresponding to the effect of these earthquakes (e.g., mean and standard deviation of the responses) can then be represented, each, as neural networks with inputs containing the remaining structural and/or soil variables. This methodology is straightforward and efficient. It separates the response calculation from the reliability or optimization task. The work presented here shows an application of the methodology to the study of a pile-supported bridge pier in soft soil, with and without consideration of soil-structure interaction, with conclusions regarding the importance of the interaction for the reliability of the pier.

### 3D TIME HARMONIC GREEN'S FUNCTIONS OF A TRANSVERSELY ISOTROPIC HALF SPACE – ID 865

*A. Khojasteh, University of Tehran, Iran (Islamic Republic Of)*
*M. Rahimian, University of Tehran, Iran (Islamic Republic Of)*
*M. Eskandari Ghadi, University of Science and Technology of Mazandaran, Iran (Islamic Republic Of)*

In this paper an exact analytical solution is presented for displacements and stresses of a three-dimensional linear Green elastic transversely isotropic half-space subjected to an arbitrary, vertical, time-harmonic surface force. The equations of equilibrium in terms of displacements are uncoupled by using potential functions. The boundary value problems for the potential functions are solved by applying Fourier expansion and Hankel integral transform with respect to angular and radial coordinates, respectively. The

development includes a set of transformed stress-potential and displacement-potential relations which are useful in a variety of elastodynamic problems. Green's functions presented in this paper are important in development of boundary-integral-equation method for analysis of dynamic anisotropic soil-structure interaction problem and seismic waves scattering in anisotropic soils. The solutions can be also used to verify the accuracy of finite element and other approximate numerical algorithms developed to analyze wave propagation problems involving transversely isotropic materials. Different numerical results for Green's functions are included to demonstrate the influence of the degree of the material anisotropy, and the frequency of excitation on the response.

### EXPERIMENTAL AND NUMERICAL RELIABILITY ANALYSIS OF DAMPING DEVICES UNDER IMPACT LOADS FROM CONTAINER – ID 886

*S. Mori, Ehime University, Japan*
*K. Motoki, Tokyo Institute of Technology, Japan*
*J. Kralik, Slovak University of Technology, Slovakia (Slovak Republic)*
*J. Cesnak, Slovak University of Technology, Slovakia (Slovak Republic)*

This paper presents the transient dynamic analysis of nuclear power plants building under impact loads. In recent time of permanent demands for increasing of active and passive nuclear power plants safety the question of estimation of the technological equipment resistance after certain operation time is very actual. One from the potential accident is the free fall of container (weight 85t) during the transport above containment. This problem was considered in accordance the soil-structure and fluid structure interaction, concrete crack, impact loads in time in FEM model on ANSYS program. The FEM model has 20 840 (structural and fluid) elements and 15 600 nodes. The hall crane transports the nuclear fuel in the steel container TK - C30 under ceiling plate at +18,90m . The cylinder container has diameter 2285mm, height 4367mm and weight 85t. In the case of accident the container can fall to the containment plate. Container free fall was modeled as an impact load. The impulse intensity and its duration are expressed from the condition of equality of the kinetic energy of a free falling body and deformation potential energy of the structure and the container. The second effect of the containment fall is the shock loads to the steam generators. The results from the dynamic analysis show that the peak accelerations are 3-5times higher than in the case of earthquake. The steel tubular damper system is proposed for dissipation of the kinetic energy of the container free fall. The shock-damper basic element behavior under impact loads was tested by experiment. The probabilistic and sensitivity analysis of the damping device reliability to absorb the kinetic energies of the container fall was realized using the direct method MONTE CARLO. Four types of the damping devices with various geometry of steel pipes in one and two layers were analyzed.

### ISOTROPIC AND DEVIATORIC COMPONENTS FOR THE 2ND AND 15TH OF MAY 1995 SEISMIC EVENTS IN LOP NOR, CHINA – ID 1838

*M. Elgabry, NRIAG, Egypt*
*K. Abou Elenean, NRIAG, Egypt*
*H. Hussein, NRIAG, Egypt*
*I. Korrat, Mansoura University, Egypt*
*A. Gharib, NRIAG, Egypt*

The moment-tensor solutions are derived for a nuclear explosion and an earthquake by using low-frequency band of data which are considered as representative for the gross properties of the rupture process averaged over tens of seconds or more. The moment tensor inversion results showed that, in the case of the earthquke the isotropic component (isotropism) equals to zero, so the total force is deviatoric reflecting its mechanism (strike-slip) and the large dimension of the earthquake source. On the other hand, in the case of the nuclear explosion the isotropic component dominates (equals to 74%) reflecting the isotropism associated usually with the small source isotropic explosions. It is also observed that the maximum eigenvalue occurred in the X-direction with less value in the other two directions reflecting that the source geometry was not spherical but very probably cylindrical.

## STS E2: Practice-oriented Nonlinear Approaches for Performance Assessment and Design

Level-1

### TWO EMPIRICAL EXPRESSIONS PROPOSED TO CALCULATE THE TARGET DISPLACEMENTS DURING PUSHOVER ANALYSIS – ID 106

*B. Taskin, Istanbul Technical University, Turkey*
*Turkey*

This paper is focused on the application of two recently proposed empirical expressions for calculating the target displacements of buildings, for which nonlinear static analysis procedures are to be performed as described in ATC-40 or FEMA-356. It is widely agreed that nonlinear static analyses are satisfying when a target displacement is encountered and commonly, this target displacement is determined from the analysis of an equivalent SDOF system. In the close past, many researchers realized studies on SDOF systems, using different structural characteristics, namely: yield strength, ductility, strain-hardening, base-shear, safety level or even various hysteretic models, within a certain period range, under the effect of strong motion records of simulated earthquake time histories. Recently, Chintanapakdee and Chopra, proposed two empirical equations to calculate the inelastic deformation demands of bilinear systems. Based on their studies, Taskin modified and proposed two empirical expressions for stiffness degrading systems. In the expressions, the inelastic deformation ratios, $C\mu$ and CR, for systems with known ductility, $\mu$, and yield strength, R, values, respectively, are easily calculated, therefore, very handy for practical use. An actual four story reinforced-concrete (RC) frame structure, which suffered moderate damage during the August 17, 1999 Kocaeli Earthquake and retrofitted afterwards by improving the structural system with a number of eight additional shear walls (four in each direction), is considered for investigation. Nonlinear analysis of the structure is realized by running Drain-2DX computer program and is taken into account as "exact" solution. Based on the displacement capability under the effects of seven strong motion records, ductility of the structure is calculated and ensemble averages are calculated. Then target displacements are calculated using the above-mentioned empirical equations and successfully compared with the nonlinear analysis calculations. Finally, modal pushover analysis for the structure is carried out, considering the target displacement value obtained from the proposed expressions.

### FULLY INTEGRATED PERFORMANCE BASED DESIGN USING NONLINEAR DYNAMIC ANALYSIS – ID 340

*J. Chambers, Holmes Consulting Group, New Zealand*
*T. Kelly, Holmes Consulting Group, New Zealand*

The Nonlinear Dynamic Analysis procedure (NDP) is the most rigorous method available to structural engineers for assessing the seismic performance of buildings. Continual improvements in computer power make this method a practical option for design office use. In addition, documents such as FEMA 356 provide comprehensive guidance for assessing the seismic performance of buildings using various analysis methods including the NDP.

The performance of individual elements will typically be assessed by comparing plastic deformations predicted by the analysis with acceptable limits specified by FEMA, or through a rational analysis, accounting for the specific detailing present in the element and its connections.

The performance assessment is typically based on envelope results obtained from the analysis. The difficulty with this is, for

some element types, the determination of the level of acceptable plastic deformation is calculated from a number of response terms. If these calculations are performed using envelope results at the end of the analysis, the level of acceptable plastic deformation can be significantly underestimated. This can lead to unnecessary works to retrofit elements that do in fact perform satisfactorily. In some cases it may make rehabilitation of existing buildings uneconomic.

In order to overcome this issue, the calculation of acceptability criteria must be performed at every time step; the performance assessment fully integrated with the analysis engine.

The present paper describes the implementation of such a "fully integrated" performance based assessment method using the ANSRII analysis engine. A number of case studies are provided which compare the results of fully integrated assessment with assessment based on envelope results obtained using the NDP. In addition, comparison is drawn with results obtained using the Nonlinear Static or Pushover analysis method. The envelope approach is shown to be at times overly conservative, leading to significantly more expensive retrofit solutions.

## VERIFICATION OF AN ADAPTIVE PUSHOVER TECHNIQUE FOR THE 3D CASE – ID 619

*H. Alves Meireles, IST and ROSE School, Portugal*
*R. Pinho, ROSE School c/o Eucentre, Italy*
*R. Bento, Instituto Superior Tecnico (IST), Portugal*
*S. Antoniou, SeismoSoft, Greece*

The displacement based adaptive pushover (DAP) procedure is an improved pushover technique that manages to take into account all the advanced features of the improved pushover techniques. It is fully adaptive and therefore accounts for stiffness degradation and period elongation, it is multimodal by setting combination rules to include higher mode effects and the site specific ground motion characteristics can be taken into account through spectrum scaling. A set of laterally imposed displacements are applied to the structure rather than forces. The technique has been extensively verified for two dimensional planar structures with improved results when compared to conventional pushover techniques. For irregular building structures, where a 3D analysis is required, its application would be even more advantageous as higher mode effects are decisive for the attainment of good results and more complex systems require improved procedures. Herein, the DAP methodology is verified for a 3D asymmetric building structure (the SPEAR building, tested at full-scale under pseudo-dynamic conditions) and the resultant capacity curves are validated by the time-history analysis results, for increasing intensities of the ground motion. For the time history analysis uniaxial and biaxial excitation is considered (taking into account possible variations in the seismic angle of incidence). Different combination rules are also tested. Good agreement is obtained with the time history analysis results especially for the uniaxial excitation. The procedure has proved to be a viable and easy to use tool for the pushover analysis of 3D structures. Further testing on different structural systems is, nevertheless, advisable in order to fully validate the procedure.

## PERFORMANCE-BASED DESIGN OF RC BUILDINGS USING OPTIMALITY CRITERIA – ID 684

*M. Fragiadakis, National Technical University of Athens, Greece*
*M. Papadrakakis, National Technical University of Athens, Greece*

A performance-based design procedure specifically tailored to handle problems of optimum design of reinforced concrete (RC) buildings is presented. The purpose is to introduce an automatic methodology for the design of RC structures using nonlinear timehistory analysis. A structural optimization algorithm is adopted in order to replace the traditional trial-and-error design process, which in the past had been an essential ingredient of design methodologies based on nonlinear analysis methods. Thus, the optimization algorithm is used as a search engine with the aim to locate the design that corresponds to the best structural performance. The best performance is defined as the combination of minimum total cost and satisfying all design requirements. The total cost is the sum of the cost of concrete and the cost of reinforcing steel. The performance is evaluated by means of "single-stripe" analysis with a suite of seven strong ground motion records, i.e. the records are scaled using 5%-damped first mode spectral acceleration to the same intensity level. Median estimates of the maximum interstorey drift demand are obtained for two performance levels. European design code checks are also imposed on the structure as constraints of the optimization problem. The optimization algorithm determines the optimum dimensions and reinforcement for each member in order to reduced the total cost and satisfy design requirements. Tables of reinforced concrete sections are formulated in order to transform the problem to an equivalent steel-structure problem and handle the large number of possible RC sections. For the solution of the optimization problem evolutionary algorithms and in particular the Evolution Strategies algorithm is adopted. The efficiency of the proposed optimization procedure is demonstrated in a case study of a two-storey RC frame. Significant cost reduction combined with better control during severe earthquakes can be achieved when the proposed methodology is implemented.

## THE RPSD METHOD AND ITS APPLICATION TO THE DESIGN OF A 12-STORY R/C FRAME – ID 803

*J. Domingues Costa, BYG.DTU, Denmark*
*M. Aono, NIT, Japan*
*T. Ichinose, NIT, Japan*
*R. Bento, DECivil, IST-UTL, Denmark*
*M. P. Nielsen, BYG.DTU, Denmark*

The paper aims to present the new seismic design procedure, the Rigid-Plastic Seismic Design (RPSD) method, and provide an example of its application. This is a straightforward design method rooted in Non-Linear Time-History Analysis (NLTHA) for systems expected to perform in the inelastic range under a lifetime earthquake event. The method is based on the Theory of Plasticity: the designer chooses the collapse mechanism as well as the corresponding safe stress field outside the hinges. These are assumed to have rigid-plastic behaviour where pinching is taken into account in a very simplified manner. The rest of the structure remains in the rigid domain throughout the whole period of the ground motion. In this way, the structure may be treated as a generalized SDOF system, the dynamical response of which depends only on the lateral strength. Thus, the seismic demand is determined in terms of a pre-defined performance parameter obtained by means of a rigid plastic spectrum. The latter is characteristic of the ground motion scenario expected at the implementation site. The final design is carried out considering a set of extreme loading cases roted in the fact that the maximum strength demand at any point of the structure is solely dependent on the intensity of the ground motion. The method is applied to the design of a 12-story reinforced concrete frame. The final results are compared by means of refined NLTHA.

## PERFORMANCE-BASED SEISMIC REHABILITATION OF R.C. BUILDINGS USING DISSIPATIVE BRACES – ID 986

*M. Ferraioli, Department of Civil Engineering - SUN, Italy*
*A. M. Avossa, Department of Civil Engineering - SUN, Italy*
*P. Malangone, Department of Civil Engineering - SUN, Italy*

In the latest years, the application of dissipative bracing systems proved to be a very efficient alternative to conventional upgrading strategies. This technique effectively combines the advantages of the steel bracing system (lightness, stiffness, ductility, user-friendliness, reversibility) and the advantages of viscous dissipative devices (increase of energy dissipation capacity and reduction of seismic damage), and it may satisfy the performance requirements of earthquake resistant design of buildings: high stiffness under low intensity earthquakes and high ductility under earthquake strong ground motions. However, the optimum design of this rehabilitation system is not so easy. The conventional seismic design based on linear-elastic analysis and on resistance, stiffness and ductility criteria and on the capacity design rule proved to be ineffective. In fact, the experience from recent strong

earthquakes demonstrated that the behaviour of many structures designed as earthquake resistant was unacceptable, because they suffered damage that was either non-repairable or too costly to be repaired. This lesson led to the development of a modern generation of performance-based guidelines for design of structures that perform appropriately for all earthquakes. In this paper, the performance-based seismic rehabilitation of r.c. buildings using dissipative steel braces was carried out. The multi-level objectives are pursued with a procedure based on the Capacity Spectrum Method, the Inelastic Demand Response Spectra and the estimation of the duration-related damage that is a function of the energy absorbed in the structure. At this aim, an extension of Park & Ang damage model and an energy-based approach were used. This procedure retains the conceptual simplicity and computational effectiveness of pushover analysis, it accounts for the cumulative inelastic deformation under displacement reversals and, when applied to r.c. framed buildings strengthened with eccentric bracing systems, it seemed to be successful in reproducing the dynamic behaviour of the rehabilitated building.

### A PERFORMANCE-BASED COMPARATIVE EVALUATION OF REHABILITATION METHODOLOGIES – ID 989

*M. Ferraioli, Department of Civil Engineering - SUN, Italy*

A great number of existing r.c. buildings are designed without seismic design criteria and detailing rules for dissipative structural behaviour. As a consequence, the seismic rehabilitation of these structures is a very interesting topic and involves not only technical and economical aspects, but also ethical and social aspects. In the upgrading process the challenge is to create a system that will deliver desired performance in a cost-effective way. At this aim, modern rehabilitation guidelines are more explicit in quantifying demand and capacity parameters that must be met to satisfy particular performance goals. Within the performance-based methodologies, the concept of force as a design parameter is abandoned leaving place to displacement, deformation and energy. In this paper a comparative evaluation of different methodologies for rehabilitation of concrete buildings in the context of performance-based engineering is carried out. A number of seismic upgrade alternatives were studied. The rehabilitation methodologies included the introduction of new structural members such as dissipative bracing systems, steel frames or r.c. shear walls, or the local increase of strength or displacement capacities through carbon fiber wrap, steel jacketing, added confining cover concrete. In compliance with the actual nature of the earthquake that represents an energy related process, a damage controlled procedure was used to correlate the different levels of performance with the displacement demand of a point that is representative of the entire building. This procedure is based on the pushover analysis, the comparison between structural capacity and inelastic seismic demand, and the estimation of the duration-related damage as a function of the energy absorbed in the structure. At this aim, a procedure based on the dynamic analysis of an equivalent SDOF system is used to characterize the hysteretic energy dissipation under seismic loading starting from the monotonic energy dissipation.

### EARTHQUAKE PERFORMANCE AND RETROFIT OF AN EXISTING BUILDING HAVING VERTICALLY IRREGULAR STRUCTURAL SYSTEM – ID 1037

*K. Güler, ITU Tech. Uni. Fac. of Civil Eng., Turkey*
*I. Ö. Kartal, Turkey*
*B. Taskin, ITU Fac. of Civil Eng., Turkey*
*M. Altan, ITU Fac. of Civil Eng., Turkey*

The earthquake performance of a vertically irregular existing building, which has been retrofitted afterwards, is investigated herein this study. This type of irregularity, which is due to non-coinciding longitudinal axes of the columns on the periphery for two neighboring stories, generally ground and the first, is not permitted anymore in the latest Turkish Earthquake Code (1998). Since these discontinuous columns within the above-mentioned two stories are connected through the corbels between two offset columns, heavy damage or even a partial collapse is frequently observed in these systems during the recent earthquake events, such as August 17, 1999 Kocaeli earthquake. Hence, the existence of a significant portion of the entire amount of residential building stock, the probability of heavy damage potential seems very high for this type of irregular building during the expected disastrous earthquake in Istanbul metropolitan city.

In this respect, a six-story building, which was designed considering the previous 1975 Earthquake Code, is 3D-modeled using SAP2000 software. After 1998 code was forced, it is understood that the base shear amount was increased 40%, therefore, a performance check is required. 2D and 3D push-over analyses are carried out for each of the x and y directions and capacity spectrum method, which is based on static push-over analysis, is used to obtain the performance levels of the existing structural system. The plastic hinge patterns are exhibited on 2D and 3D structural systems. Since the lack of load carrying capacity of the system, the structure is strengthened by introducing four L-shaped shear walls connecting the corner columns. The strengthened system is analyzed similarly and performance evaluation is realized, based on the demand and capacity curves. Furthermore, comparisons are carried out and discussed in details, for as-built and strengthened states of the building.

### SEISMIC RELIABILITY ANALYSIS OF COMPLEX NONLINEAR SYSTEMS, USING STIFFNESS-REDUCTION INDICATORS – ID 1068

*O. Díaz-López, National University of Mexico, Mexico*
*L. Esteva, National University of Mexico, Mexico*

For applications to performance-based seismic design, the estimation of the reliability of complex nonlinear systems for given values of the ground-motion intensity has often been based on a second-moment probabilistic description of the safety margin Z, defined in terms of the dynamic response and the deformation capacity of the system. This permits to express the reliability in terms of Cornell's index $\beta$(y), where y is the earthquake intensity. Typically, probabilistic estimates of the deformation capacities of complex systems are obtained by means of pushover analysis. However, this approach is not capable of accounting for a) the dependence of the lateral deformation capacity on the response configuration of the system when it approaches failure, and b) the influence of cumulative damage associated with the cyclic response. In this paper an alternative approach is presented, which aims at estimating reliability functions $\beta$(y), including the influence of cumulative damage and avoiding the need to obtain probabilistic definitions of lateral deformation capacities. For this purpose, a damage indicator D(y) is defined as the ratio (K0 – K(y)) / K0, where K0 is the value of the secant stiffness of the system when it responds in its linear range of behavior to earthquake excitations and K(y) is the value of its secant stiffness when subjected to an earthquake with intensity equal to y. The problem of determining $\beta$(y) is transformed into one of estimating the mean and the standard deviation of the value of the minimum intensity necessary to produce a value of D equal to 1.0 (collapse condition). The paper presents an algorithm for this purpose, based on Monte Carlo simulation. It ends with a comparison of the reliability functions determined in accordance with the approach just described and others available in the literature.

### SEISMIC PERFORMANCE EVALUATION PROCEDURE FOR REGULAR AND IRREGULAR BRIDGES – ID 1319

*A. G. Ayala, ELSA, Joint Research Centre, Italy*
*M. Niño, ELSA, Joint Research Centre, Italy*
*T. Isakovic, University of Ljubljana, Slovenia*

This paper describes a simplified procedure for the performance based seismic evaluation of bridges, based on the definition of a non-linear response curve for a reference single degree of freedom system corresponding to the mode which contributes the most to the response of these structures. This curve is obtained

through non-linear modal spectral analyses taking into account the contribution of higher modes of vibration. The procedure is based on one previously used for the evaluation of multi-storey buildings where through a multi-mode pushover analysis the response curve of a simplified reference system is obtained and from it the seismic performance of the structure is determined. This procedure is modified by using for the definition of the response curve of the reference system, modal spectral analyses which take into consideration, in an implicit way, the displacement reversal characteristic of the earthquake action, and the participation of higher modes of vibration of importance in the evaluation of bridges which response is governed by more than one mode of vibration and the transient nature of earthquake action. To illustrate the application of the procedure, the results of two bridges, one regular and another irregular are obtained with this methodology for earthquakes of various intensities given by the design spectrum of Eurocode 8. The obtained results are compared with the mean of the inelastic step by step dynamic analyses using an assemble of earthquake records congruent with the design spectrum of this code.

### PERFORMANCE BASED SEISMIC ASSESSMENT AND DESIGN – ID 1372

*A. G. Ayala, ELSA, Italy*
*P. Negro, ELSA, Italy*

This paper presents a unified approach for the seismic evaluation and design of structures consistent with the performance-based seismic design philosophy. In the paper, the strengths and limitations of current seismic evaluation and design practice and the current tendencies in emphasizing the seismic performance on the assessment and design are discussed. The approach uses a two-way procedure which considers the non-linear behaviour of the structural elements, performance indices accepted by current seismic codes, uniform hazard seismic design spectra and in the case of 3D buildings bi-directional earthquake action. To illustrate the application of the seismic evaluation and design procedure a typical reinforced concrete plane frame is used as example. The frame is firstly designed in accordance with the latest version of Eurocode 8, then by the design way of the procedure of this paper and finally both designed frames are evaluated using the same procedure of the performance-based designed frame. The frame is designed and evaluated for a basic design objective with a life safety performance level and a design level corresponding to a design spectrum with a given exceedence rate of the chosen performance index. For validation purposes, results of non-linear step by step analyses of the two designed structures are presented and their results discussed when compared with those obtained from the evaluation procedure. The potential of the design procedure to produce expected global but not necessarily local performances is discussed.

### SOME REMARKS ON THE SEISMIC ASSESSMENT OF RC EXISTING BUILDINGS IN ITALY ACCORDING TO RECENT CODES – ID 1375

*C. Faella, Dept. of Civil Engineering, University of Salerno, Italy*
*D. De Santo, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Martinelli, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Nigro, Dept. of Structural Analysis and Design, Italy*

Seismic assessment of existing structures is one of the most common tasks to be faced by the today structural engineers, which are often charged of evaluating the seismic response of non-seismically-designed constructions and checking their fitness against the expected seismic action. The New Italian Seismic Code, which is basically inspired to Eurocode 8, provides the structural engineer with various methodologies for assessing the seismic behavior of existing structures, all conceived according to the Performance Based Approach. Non-linear static (pushover) analysis is one of such methodologies; it is able to reproduce the non linear response of a framed structure pointing out, among the other things, its elastic threshold, the overstrength ratio and the global displacement capacity. The present paper proposes some remarks deriving by the fulfillment of the code provisions to a wide group of existing RC school buildings lying in Campania Region (Italy) which have been surveyed and modeled through static non linear analysis. Static Pushover analyses and N2-Method are utilized for determining displacement capacity and demand with reference to the various performance objectives introduced by the code. A synthetic measure of seismic vulnerability of each structure can be obtained in terms of the demand-to-capacity displacement and base acceleration ratios. These synthetic parameters are hugely affected by the mechanical models considered for simulating the non linear behavior of existing members; consequently, a comparative analysis of the results obtained through different definitions of plastic rotations, different hypotheses on cracking in RC members and material properties will be also proposed. Besides the mere comparison between demand and capacity, other consistent measures are generally needed for qualifying the characteristics of the inelastic structural behavior; these measures will be introduced in the paper and will be useful for addressing the choice of the most effective retrofitting techniques.

### THE IMPLEMENTATION OF BUCKLING RESTRAINED BRACED FRAMES IN THE UNITED STATES – ID 1475

*E. Ko, Arup, United States*
*C. Field, Arup, United States*

Arup had successfully employed the Buckling Restrained Brace (BRB) on a number of Japanese projects before introducing it to California in 1999. Consequently Arup has been involved with rigorous research, testing and verification of the new system.

This paper discusses the implementation, research and design procedures that were developed for the first building and subsequent first hospital project in California to use the Buckling Restrained Braced Frame (BRBF) for its seismic system.

This involved the establishment of relevant design criteria and the testing and analytical modelling of the component and system. Our analytical modelling indicated issues with the connection performance which were consequently researched and documented and verified through physical testing.

To date, over 10 million square feet of buildings incorporating this new technology have been constructed in the seismically active region in the Pacific Northwest. The performance of this system will be compared and discussed with other popular systems such as moment resisting frames and special concentrically braced frames and guidance will be given on the design and detailing of the BRBF system.

### AN INNOVATIVE STRATEGY FOR PERFORMANCE ASSESSMENT AND EARTHQUAKE RETROFITTING OF WOODFRAMED BUILDINGS – ID 1688

*H. Kawakami, Geosphere Research Institute, Saitama University, Japan*
*E. A. Tingatinga, Graduate School of Science and Engg, Saitama Univ., Japan*
*H. Y. Chang, Geosphere Research Institute, Saitama University, Japan*

In Japan, the majority of modern residential and a fraction of commercial structures are woodframed construction. The vast number of woodframed buildings is critical to the infrastructure of the country and their continued good performance is integral to the overall economic welfare. When these buildings need structural reinforcement, structural engineers must confer with the building owner before carrying out appropriate retrofit methods. A retrofit plan may not be implemented if the structural engineer can not have the building owner understand the performance assessment of the building. To address the above issues, a new methodology was developed for the seismic performance assessment and retrofit strategy for woodframed buildings. This methodology identifies local failures such as column buckling and connection fracture, which may induce the global system to collapse, and then reinforces the system by adding stiffness or strength to the weak members.

In this study, a three-dimensional finite-discrete element method, which can describe the elastic-plastic behaviour of a structure and simulate the progressive collapse process, was employed. The sequence of the analysis and results in the form of computer animations are then used to help the building owners gain a better understanding of the seismic performance of their buildings before and after the structural reinforcement. Finally, an application to a real woodframed residential building was used as an example to show the effectiveness of the methodology in seismic performance assessment as well as retrofit plan development.

## STS E3: Irregular Structures.

Level-1

### SEISMIC VULNERABILITY OF INFILL FRAMES – ID 72

*A. K. Sinha, C.M.E, India*
*P. R. Bose, D.C.E, India*

Seismic Vulnerability Assessment and Retrofitting of Existing Buildings is a key area in Civil Engineering in general and Earthquake Engineering in particular. Earthquakes find weaknesses left behind by us in structures. Seismic damage concentrated at weak zones of structure speaks of as a report by a perfectionist 'The Nature'. The fact is beyond any doubt that the widespread damage to structures and immense losses are not due to just natural act but due to either our negligence or our ignorance. Earthquake Engineers can contribute in the noble cause of seismic disaster mitigation by assessing seismic vulnerability of existing buildings and providing the structure safe capacities against the anticipated demands during expected ground motion. The paper is in the direction discussed above. There are scores of reasons for seismic vulnerability of existing infilled RCMRF buildings. Merits and demerits of having infill and its impact over the seismic performance have been enumerated in the paper. The earthquake resistant philosophy being practiced all over the world accepts structure going well into inelastic zone during strong motion. A method centered on Pushover analysis has been proposed to quantify structural response in inelastic zone in view to assess seismic vulnerability. RC MRF with masonry infills presents very different situation, which warrants third tier of assessment methods. Study of uniform and non-uniform distribution of masonry infills using the Pushover based method provides enough guidelines to refine and supplement our knowledge in dealing with such structures as a rational seismic vulnerability leads to appropriate retrofit strategy for the existing structures.

### SEISMIC BEHAVIOR OF A TWO-TOWER SETBACK STRUCTURE: – ID 382

*D. Kusumastuti, Bandung Institute of Technology, Indonesia*
*A. Reinhorn, University at Buffalo, United States*
*A. Rutenberg, Technion, Israel*

Due to architectural and functional demands many buildings are irregular in plan and elevation. Setbacks and multiple towers are quite common such configurations. These buildings are seismically vulnerable due to abrupt variations in strength and stiffness producing non-uniform displacement demands, and stress concentrations. This experimental and analytical study focuses on the applicability of standard displacement-based analytical tools to predicting the seismic response near collapse of such buildings, with special emphasis on progressively refining the analytical model as knowledge of properties becomes available from the experimental results. Another purpose was development of a versatile model to study irregular structural systems with different configurations. A reconfigurable structural model with replaceable sacrificial elements was developed to be used and reused for structures undergoing severe damage. Avoidance of complete collapse was achieved by two independent support systems - one for gravity and one for lateral loads; hence, loss of lateral resistance during earthquakes leaves gravity columns undamaged, thereby preventing collapse. Shake table tests on a two-tower model were conducted by applying ground motions with increasing intensities. At the higher motion levels, the model behaved inelastically. Damage due to prying action at column endplates and welding failure of a block joint located at the higher tower toes were observed. Separation of vertical and lateral load resisting systems was satisfactory as the model suffered complete column connections ruptures without total collapse. Most of the structural elements were undamaged and in fact have been reused. Improved analytical models based on the test results were developed following the various experimental stages. A new form of push-over analysis using norm superposition of instantaneous modes proved to fit spatially irregular structures, thus allowing an extension of simplified evaluation procedures. The experimental study provided the data for verification of the simplified procedure.

### BEHAVIOR OF ASYMMETRIC MULTISTORY BUILDINGS WITH DIFFERENT STRENGTH DISTRIBUTION – ID 399

*A. Aziminejad, IIEES, Iran (Islamic Republic Of)*
*A. S. Moghadam, IIEES, Iran (Islamic Republic Of)*
*W. K. Tso, McMaster University, Canada*

When a multistory building vibrates in linear range, the eccentricity between centers of rigidity and mass is a valid measure of asymmetry of the building. When the building vibrates in nonlinear range, for example during a powerful earthquake, stiffness and therefore location of center of rigidity of building is continuously changes. As no longer the location of center of rigidity is constant, center of strength is a better measure of torsional response in nonlinear range of behavior. Thus for controlling torsional damages due to building asymmetry, both locations of centers of rigidity and strength with respect to center of mass, are important. Recent studies on single story building models revealed that appropriate configuration of these centers is effective in reducing torsional damages. The present study extends the same approach to multistory asymmetric buildings. The nonlinear responses of multistory building models subjected to earthquake excitations with different strength and stiffness eccentricities are compared. The results show that use of appropriate configuration of these centers is also very effective in limiting torsional damages in multistory buildings. However for each specific damage parameter, there is a specific configuration of centers of mass, rigidity and strength that minimizes the damage. As such, for seismic resistant design of a multistory asymmetric building, the best configuration of different centers may be identified only after selecting the critical parameter or a combination of parameters as the best indicator of damage for the building under investigation.

### SEISMIC ENERGY DISTRIBUTION IN ONE-STORY IRREGULAR STRUCTURES UNDER BI-DIRECTIONAL GROUND MOTION – ID 460

*M. Iancovici, Technical University of Civil Engineering, Romania*

Complementary to the conventional analysis approach, the energy balance-based analysis has the potential to describe synthetically and more efficiently the contribution of each component to the dynamic equilibrium of structures. The input energy induced into a structural system by a strong ground motion is an important evaluation parameter of an earthquake destructive potential. It includes both, the ground motion characteristics and the structural dynamic properties, the strong motion duration being explicitly accounted for. The paper investigates the stiffness irregularity effect on the time-history and peaks of energy balance distribution in one-story elastic buildings, subjected to bi-directional ground motion, applied under a 10o rosette from the main stiffness axes of the model. Through a linear energy-balance analysis, modal and total energies are computed and the input energy distribution coefficients are obtained in order to assess the structural damage exposure of highly irregular structures.

### SIMPLIFIED METHOD FOR THE EVALUATION OF THE TORSIONAL DISPLACEMENT AMPLIFICATION – ID 765

*D. Zamfirescu, Technical University of Civil Engineering, Romania*
*T. Postelnicu, Technical University of Civil Engineering, Romania*

Recently, the displacement-based methods for the assessment of seismic performance of structures became widely used in design. The present work is proposing a simplified method for the evaluation of the displacement amplification due to torsion within the framework of the CSM (Capacity Spectrum Method). The procedure is based on the Response Spectrum Analysis of a two-degree of freedom system (one translation – one twist) having the rotational and translational stiffness properties altered according to the CSM algorithm. Basically, the following steps have to be followed: 1.Define equivalent linear system using maximum displacement in translation. The torsional stiffness of the equivalent system is decreased with respect to the ratio of initial and equivalent translational periods. 2.Based on initial uncoupled frequencies, the natural coupled frequencies and mode shape vectors can be analytically obtained using the altered stiffness properties determined at step 1. 3.Compute the individual modal displacements at the significant locations of the building using the overdamped displacement spectrum and then combine the individual responses. The described algorithm was applied for two one storey simple test structures. The first structure is torsionally unrestrained having no lateral resistant elements laying on the direction perpendicular to earthquake action. The other one is derived from the former, by introducing two elements on the direction perpendicular to the earthquake action, that restrain the twist. The results of the simplified procedure were compared against the results obtained by nonlinear dynamic analysis of the test structures. The bidirectional action effect was also investigated by the dynamic analysis and was found to be negligible justifying in that respect its elimination within the proposed simplified procedure. The results offered by the simplified procedure are reasonable close and what is more important, similar in variation with the ones computed by the time-history analysis.

### NON-LINEAR ANALYSIS OF SEISMIC BEHAVIOUR OF ASYMMETRIC IN PLAN BUILDINGS – ID 853

*D. Ladjinovic, University of Novi Sad Faculty of Technical Scienc, Yugoslavia*
*R. Folic, University of Novi Sad Faculty of Technical Scienc, Yugoslavia*

Building with asymmetric distribution of stiffness and strength in plan undergo coupled lateral and torsional motions during earthquakes. In many building structures, the centres of resistance do not coincide with the centres of mass. As a consequence, lateral base motion during an earthquake gives rise to torsional vibration of the structure. The inelastic seismic behaviour of asymmetric-plan buildings is considered using the histories of base shear and torque. The procedure to construct the base shear and torque (BST) surface of the system with an arbitrary number of resisting planes in the direction of asymmetry and of ground motion is proposed. Several factors that control the shape of this surface are identified. The BST surface is defined by the set of base shear and torque combinations corresponding to the different plastic mechanisms that can be developed in the system. The base shear and torque response histories, especially with the BST surface, may be a useful tool for conceptual seismic design of asymmetric-plan buildings. The factors that determine the shape of the BST surface and influence the inelastic behaviour are the strength eccentricity, lateral and torsional capacity of the system and plan wise distribution of strength. Stiffness eccentricity does not affect the shape of the BST surface, but it controls where on this surface the system develops its inelastic behaviour. The BST surface contains most of information necessary to describe the inelastic properties of a system. Its shape is directly related to the yielding mechanisms of the structure and, thus, controls the relative displacement demand among resisting planes. Inelastic behaviour of the system is represented in this force space as motions along the surface. However, the inelastic deformation cannot be computed from the BST surface unless a non-linear static or dynamic analysis is performed.

### INELASTIC SEISMIC BEHAVIOUR OF ASYMMETRIC MULTI-STORY BUILDINGS TO NEAR FIELD GROUND MOTIONS – ID 874

*B. K. Raghu Prasad, Indian Institute of Science, India*

The focus of the study is on inelastic seismic behaviour, near field ground motion effects and design of asymmetric multi-story buildings, emphasizing the use of displacement demand. To quantitatively assess the performance of multi storey buildings to near field ground motions, strong motion records from Imperial valley (15th October1979;Mw=6.6),San Fernando (20th September 1971;Mw=6.6) and Northridge (1st January 1994;Mw=6.6) earthquakes are considered and the following different structural characteristics and their effect on the response of the buildings are analyzed: Influence of shape of building in plan, effect of masonry infill, Stiffness asymmetry, Strength asymmetry, Plan wise distribution of strength and bi-directional ground motion. Results indicate that the impulsive character of the near-field ground motion gets reflected in the derived displacement response of the structure. As results of these analyses few shortcomings are noticed in present codal provisions in strength and stiffness distribution.

### SEISMIC PERFORMANCE OF RC STRUCTURES DESIGNED FOR ACCIDENTAL ECCENTRICITY – ID 901

*A. D'Ambrisi, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. De Stefano, Dipartimento di Costruzioni, Università di Firenze, Italy*
*M. Tanganelli, Dipartimento di Costruzioni, Università di Firenze, Italy*

In order to account for uncertainties in the location of center of mass on the floor slab and in the spatial variation of the seismic motion, seismic codes introduce the so-called accidental eccentricity. Generally, the Eurocode 8 (EC8) considers the accidental eccentricity by requiring that the center of mass at each floor be displaced from its nominal location in each direction at a distance equal to 5% of the floor dimension. However, if the simplified lateral force method can be applied, then, according to EC8, the effects of accidental eccentricity may be accounted for in a different manner, i.e. by amplifying the action effects in individual load resisting elements. Furthermore, if the modal response spectrum analysis is applied, then the effects of accidental eccentricity may be determined as the envelope of the effects resulting from the application of static loadings, consisting of sets of torsional moments. In this paper, a practically symmetric 4-story RC building is designed according to the above different specifications for accidental eccentricity. A comparison is carried out regarding design member forces obtained from application of the three specifications. Furthermore, nonlinear dynamic analyses are conducted in order to assess the building response under severe earthquakes in the presence of accidental eccentricity due to mass uncertainty only, as design is conducted with the three different specifications. A suite of 20 accelerograms, generated within the SAC Steel Project for the Los Angeles area, having a probability of exceedance of 10% in 50 years, has been considered as seismic input. Local and global damage parameters are computed in order to define performance levels attained by the structure during seismic excitation. From response analysis it emerges that displacing the mass center at a distance equal to 5% of the floor dimension perpendicular to the direction of the seismic action is the most effective design specification.

### EFFECTIVENESS OF THE "ALPHA" METHOD FOR ESTIMATING THE MAXIMUM ROTATIONAL RESPONSE OF ECCENTRIC SYSTEMS – ID 958

*G. Gasparini, DISTART - Department of Civil Engineering, Italy*
*S. Silvestri, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*

In previous research works, the author have identified a key system parameter which controls the maximum rotational response under free and forced vibrations of one storey-linear elastic systems representative of asymmetric seismic isolated building structures. This parameter, called ALPHA, is defined as the mass radius of gyration of the structure multiplied by the ratio of the maximum rotational to the maximum longitudinal displacement response developed by a one-story eccentric system in free vibration. A compact exact closed-form solution for the ALPHA parameter is given for undamped systems. ALPHA parameter has also led to the identification of a simplified procedure (called ALPHA method) for the estimation of the maximum rotational response of such systems. Main goal of this paper is to verify the properties of the ALPHA parameter and the predictive capabilities ALPHA method, when applied to one storey systems representative of generic asymmetric building structures. The verification is carried out through a comprehensive set of numerical simulations carried out with reference to a number of representative structures (both linear and non linear) subjected to historically recorded earthquake ground motions, with special attention devoted to the identification of the sensitivity of the ALPHA parameter and ALPHA method upon the fundamental period of vibration of the structure (not yet considered in previous research works). The results obtained (a) confirm the effectiveness of the ALPHA parameter to capture the intrinsic propensity of an eccentric system to develop a torsional response, (b) confirm the capacity of the ALPHA method to effectively estimate the maximum rotational response of a given eccentric system under seismic excitation, and (c) indicate that the ALPHA method is only weakly sensitive upon the period of vibration of the structure, (c) indicate that the proposed ALPHA method when applied to non systems allow a conservative estimation of the maximum rotations.

### DISPLACEMENT-BASED SEISMIC ASSESSMENT OF TORSIONALLY IRREGULAR WALL STRUCTURES – ID 979

*T. Ha, Seoul National Univ., Korea, Republic Of*
*S. G. Hong, Seoul National Univ., Korea, Republic Of*

Torsional behavior of eccentric structure under seismic loading may cause the stress and/or stress concentration, which arouse the failure of the structure in an unexpected manner. This study aims to propose a seismic assessment method for eccentric wall structures based on torsional mechanism. The seismic safety will be assessed on the coordinate of lateral displacement and rotation angle including displacement capacity and demand estimation. To find the seismic displacement demand effectively a simplified torsional analysis method, which adopts the adaptive pushover concept to cover inelastic range, will be introduced. In addition, seismic assessments of several single- and multi- story structures are presented.

### AN ADAPTIVE MULTIPLE MODE NONLINEAR STATIC ANALYSIS PROCEDURE FOR IRREGULAR STRUCTURES – ID 1184

*E. Yuksel, Istanbul Technical University, Turkey*
*A. Reinhorn, University at Buffalo, United States*

The nonlinear static procedure based on pushover analysis has been recognized as a standard tool to estimate and predict the inelastic response quantities of existing and new structures, (ASCE 2000, CEN 2003). The force-deformation curve (or the spectral capacity diagram) obtained from pushover analysis of a multi degree of freedom system depends on the distribution of the lateral forces. An adaptive Euclidean Norm is suggested to obtain the effect of dominant modes in the definition of lateral forces. The adaptive dominant mode forcing function accounts for the yield of the structure since it is recalculated and it is changing from step to step. The Euclidean Norm is a superposition technique used to give precedence or strength to the important values in a summation. The higher the order of the norm, the superposition will emphasize the dominant mode which is not always the first and not always the same throughout the analysis. If the order of the Euclidean Norm is chosen as an odd number, the relative sign of vibration mode is preserved throughout the superposition. An example based on a model of a three-bay three-story steel structure with two unequal towers that was tested on a shake table at University at Buffalo's Structural Engineering and Earthquake Simulation Laboratory (SEESL) was selected for verification. The analytical model is developed using two lateral load resisting frames with irregular configuration. The analyses using the new version of the program IDARC3D were performed for the irregular model, both statically and dynamically and are subject of this paper. Contacts: eyuksel@ins.itu.edu.tr

### INCREMENTAL DYNAMIC NONLINEAR ANALYSIS OF TORSIONALLY SENSITIVE BUILDINGS – ID 1373

*G. Penelis, AUTH, Greece*
*A. Kappos, AUTH, Greece*

The paper focuses on the evaluation of the results of dynamic nonlinear time history analysis of single-storey and multi-storey torsionally sensitive buildings, highlights its limitations, and investigates the appropriate way to use them for constructing 'dynamic pushover curves' that describe both the strength and the ductility of the buildings. Single-storey monosymmetric buildings using unidirectional, as well as bi-directional, excitation, as well as multi-storey monosymetric buildings (4-storey and 8-storey) are analysed, using four different sets of accelerograms. These four sets consist of the following: 3 European earthquakes, 3 Greek earthquakes, 10 large magnitude ($\mu$=6.5-7.5) international earthquakes, and 10 medium magnitude ($\mu$=5.5-6.5) international earthquakes. The results of these parametric nonlinear analyses shed some light on important issues of 3D nonlinear analysis of asymmetric buildings. One important issue is the use of Incremental Dynamic Analysis in the case of torsionally sensitive buildings. In contrast to the case of torsionally restrained buildings, plotting the IDA (or 'dynamic pushover') curve, in the case of torsionally sensitive buildings, requires the correct choice of values (maximum displacement, corresponding base shear +/- one step) since any other choice of values leads to an overestimation of the capacity curve of the building. This issue is clearly a critical one, since to date most IDA curves were plotted from the maximum displacement – maximum base shear values, which for 2D problems is not a problem. Another important issue is the dispersion of the dynamic analysis results regardless of the scaling technique, which for torsionally unrestrained buildings is very high, due to their post yield behaviour that is dominated by a "torsional mechanism". The estimation of the torsional restraint that would be required to avoid such a behaviour, or the application of capacity design techniques in the design of the structural layout of a building, are also discussed.

## STS E4: Displacement Based Design: Initial Versus Secant Stiffness

Level-1

### EVALUATION OF R-M-T RELATIONS FOR STIFF STRUCTURES – ID 766

*I. Kazaz, METU, Turkey*
*A. Yakut, METU, Turkey*

Simplified procedures have been recommended for determining the seismic inelastic deformation demands of structures to be used in performance-based procedures. These procedures are generally based on comprehensive analyses of single degree of freedom (SDOF) systems subjected to selected ground motion records. R-m-T relations that are proposed based on these analyses are widely used in these procedures. Although the range of

parameters covered in these analyses included stiff structures, the applicability of these relations to the real stiff structures has not been investigated thoroughly. This research aims at evaluating the currently proposed R-m-T relations for investigating their validity for stiff structures. A 1/3 scale shear wall structure tested experimentally was modeled and analyzed numerically under 55 ground motions. Its response compared with the existing R-m-T relations led to significant disagreements indicating that those relations are not proper for such stiff structures. Additional analyses using more ground motion records and several parameters representing stiff structures have been carried out and the results were compared with the existing procedures. It has been observed that the efficacy of the existing procedures depends on the yield strength and post elastic stiffness of the pushover curve computed for the structure.

### INFLUENCE OF CAPACITY CURVE APPROXIMATIONS ON SEISMIC RESPONSE – ID 1033

*K. Kadas, METU, Turkey*
*B. Binici, METU, Turkey*
*A. Yakut, METU, Turkey*

Performance based engineering generally relies on the approximate procedures that are based on the use of capacity curve derived from pushover analysis. The most important parameter in the displacement-based approach is the inelastic deformation demand computed under a given seismic effect. The Capacity Spectrum Method and the Displacement Coefficient Method are the most common procedures employed for the estimation of inelastic displacement demand. Both of these procedures are based on bi-linearization of the capacity curve. Although there are some recommendations for this approximation, there is vital need for rational guidelines towards the selection of the most appropriate method among several alternatives. In view of this, a comprehensive research has been undertaken to study the influence of several existing alternatives used for approximating the capacity curve on the inelastic displacement demand. A single degree of freedom system (SDOF) associated with a fundamental period of vibration and load deformation curve (capacity curve) was analyzed under a comprehensive ground motion database. A parametric study employing the most common shapes of capacity curves was carried out. The capacity curve of the SDOF was approximated using the FEMA 356, the Initial stiffness and the Major yield approaches to determine the inelastic displacement demand. The results obtained for each case were compared with the ones computed using the actual capacity curve. The error statistics corresponding to each method are presented among with the recommendations highlighting the most appropriate procedure.

### SIMPLIFIED MODELS FOR STIFFNESS AND ENERGY DISSIPATION OF RC PIERS FOR THE DBD OF BRIDGES – ID 1088

*C. Paulotto, ELSA, Italy*
*A. G. Ayala, ELSA, Italy*
*F. Taucer, ELSA, Italy*

Current seismic design tendencies for RC bridges, in which target performances need to be guaranteed under design conditions, involve, even in the most simplified methods, an accurate description of the stiffness and energy dissipation characteristics of the piers forming the substructure of a bridge. An accurate definition of the structural properties for the piers of a bridge involves not only the use of sound analytical techniques, but also their calibration against existing results from experimental tests and refined analytical models on large scale specimens. In this paper the stiffness and energy dissipation characteristics of RC rectangular hollow bridge piers are investigated. The work involves three different levels of model sophistication namely: a continuous non-linear model without energy dissipation derived from non-linear finite element analyses; an equivalent bilinear hysteretic model derived from the originally developed non-linear model, with energy dissipation in the case of having pinching behaviour; an equivalent linear viscoelastic model with characteristics secant to yield stiffness and equivalent damping. The correctness and adequacy of the developed models are discussed within the framework of performance based design and evaluation of RC bridges.

The desired complete title of the abstract is " Simplified models for stiffness and energy dissipation characteristics of RC piers for the DBD of bridges"

## STS E6: Seismic Assessment and Retrofit of Bridges

Level-1

### A SEISMIC SAFETY VERIFICATION METHOD FOR STEEL BRIDGES WITH STEEL H-SECTION MEMBERS – ID 62

*T. Usami, Nagoya University, Japan*
*X. Ma, Nagoya Universuty, Japan*

The objective of the present research is (1) to analytically investigate the inelastic behavior of H-section beam-columns in cyclic lateral loadings (2) to propose a seismic safety verification method for steel bridges with H-section members, and (3) to present a numerical example using a steel arch bridge with H-section arch ribs. Cantilever H-section members with various dimensional and loading parameters are subjected to combined axial force and cyclic lateral loadings, both about strong axis and weak axis. The numerical method employed can take into account the effects of local, flexural and lateral-torsional buckling in both monotonic and cyclic loadings. Validity of the numerical model is first confirmed through comparison with experimental results. The numerical results are then summarized to elucidate the failure mechanisms, and the difference of failure modes in cyclic loading from those in monotonic loading is highlighted. Based on the findings in the numerical study, an empirical failure strain formula for H-section members in strong and weak axis loadings is developed. Finally as an example, an existing steel arch bridge with H-section arch ribs is utilized to demonstrate the efficiency of the proposed seismic safety verification method.

### SEISMIC RETROFITTING OF PLATE GIRDER BRIDGES BY BOLTED STIFFENERS – ID 400

*A. Vasseghi, IIEES, Iran (Islamic Republic Of)*

Plate girder bridges are the most common type of steel bridges in the span range of 30 to 90 meters. During an earthquake the girders in such bridges which are usually fabricated with slender webs could experience high shear forces near the support especially when the bridge is located near an active fault. Transverse stiffeners could be installed on the web in order to improve the shear capacity of the girders. For new bridges the stiffeners are usually welded to the web in the fabrication shop. However, due to problems associated with field welding and fatigue, welded stiffeners are not suitable for retrofitting existing bridge girders. For such purposes, bolted stiffeners are far more suitable than welded stiffeners because installation of bolted stiffener does not require field welding.

The design requirements in various bridge design specifications are based on experimental and analytical study of plate girders with welded stiffeners. Such requirements are not entirely applicable to girders with bolted stiffeners. This paper presents the results of an analytical study into behavior of plate girders with bolted transverse stiffeners. In this study finite element analysis are performed on girders with web slenderness ratio ranging from 100 to 160 and panel aspect ratio ranging from 0.5 t0 1.5. The FEA model includes both material and geometric nonlinearities in order to model the post buckling capacity of the girders. Based on this study design requirements are developed for plate girders reinforced by such stiffeners.

### TWO WAYS OF ASSESSING THE SEISMIC VULNERABILITY OF BRIDGES – ID 903

*P. Delgado, Instituto Politécnico de Viana do Castelo, Portugal*
*M. Marques, Faculdade de Engenharia da Universidade do Porto, Portugal*
*R. Monteiro, Faculdade de Engenharia da Universidade do Porto, Portugal*
*R. Delgado, Faculdade de Engenharia da Universidade do Porto, Portugal*
*A. Costa, Universidade de Aveiro, Portugal*

Significant damages, from personal, structural or even social nature, have always been associated to earthquakes. Additionally this is a random and unpredictable natural phenomenal. So it is recognized the importance and the need for a structural vulnerability assessment, in order to assure eventual adjustments in the seismic response capacity of existent or future structures. The paper focus on seismic vulnerability analysis of bridges and it is intended to estimate in a confident way the susceptibility level of this kind of structures to horizontal loads, namely, the seismic action. To accomplish this two methodologies are considered, one more accurate and the other based on a simplified procedure. The first consists on obtaining the failure probability of the structure, using a two dimension structural model; whereas the second is based on the maximum displacements allowed by the bridge. The main steps of the methodology are described and are applied to a set of bridges, trying to conclude about the corresponding seismic safety. Five typical Portuguese viaducts, differed in number and length of spans and piers, were selected, all over the country, to perform the analysis. Finally the paper tries to establish a correlation between the referred accurate and simple methodologies.

### SEISMIC RETROFIT OF RECTANGULAR CONCRETE COLUMNS BY EXTERNAL PRESTRESSING – ID 1208

*M. Sadoughi Yarandi, University of Ottawa, Canada*
*M. Saatcioglu, University of Ottawa, Canada*

Performance of bridges during recent earthquakes, demonstrated the susceptibility of concrete columns to structural damage. In particular, it was observed that bridge columns erected prior to 1970's lacked proper seismic design and detailing practices, leading to complete structural collapse. Since it is not feasible to remove and rebuild previously built bridge infrastructure, the only viable approach remains to be retrofitting these structures for improved strength and ductility. A number of different techniques are currently utilized to improve seismic performance of concrete columns. These include steel jacketing, reinforced concrete jacketing, FRP wrapping and a recently developed technique of transverse prestressing, known as "Retro-Belt." Retro-Belt is a technique developed at the University of Ottawa Canada, and involves external prestressing existing concrete columns by means of steel strands and specially designed anchors. It utilizes active and passive lateral pressure provided by transverse prestressing in controlling diagonal tension cracks created by shear, delaying brittle shear failure, improving concrete confinement and provide lateral clamping forces in reinforcement splice regions, especially in column hinging regions, thereby eliminating the slippage of spliced reinforcement. The current phase of research involves rectangular concrete columns with shear, flexure and spliced longitudinal reinforcement deficiencies in potential plastic hinge regions.

Experimental research was conducted to investigate the effectiveness of external prestressing as a seismic retrofit methodology for rectangular bridge columns. Six full-scale specimens, with a 350 mm by 700 mm cross-section, were designed, built and tested under simulated seismic loading. The specimens represented a segment of a bridge column between the footing and point of inflection. The columns were built in pairs with one column in each pair representing as-built conditions while the other column retrofitted by external prestressing. The results showed improved column deformability due to concrete confinement. The presentation will demonstrate the experimental program employed and the test results obtained.

### EVALUATION OF FRAGILITY CURVES FOR BRIDGES - A CASE STUDY – ID 1435

*V. Lekidis, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*T. Makarios, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*C. Karakostas, Inst. Eng. Seismology & Earthquake Eng. (ITSAK, Greece*
*A. Kappos, Dpt. Civil Engng., Aristotle Univ. of Thessaloniki, Greece*

Several procedures, based on either analytical or empirical data, have been recently proposed in the literature for the assessment of the vulnerability of bridges, but the subject is still open to research and without any widely established procedure. In the present paper, a methodology for the evaluation of fragility curves for bridges is presented, which makes use of static pushover analysis procedures in combination with the method of demand and capacity spectra and definitions of damage levels compatible to the pushover curves. The proposed methodology is applied for the case of a 170m long, T-shaped bridge with pre-stressed R/C curved girder box of variable height, monolithically connected to the central pier and resting on elastomeric bearings at the abutments. The above bridge is representative of a series of similar bridges on Egnatia Highway, which crosses Northern Greece in an E–W direction. The proposed methodology is simpler than those already proposed in the literature, and can thus be more easily applied for the evaluation of fragility curves for bridges of different structural types, thus contributing towards a more reliable evaluation of their seismic risk.

### ANALYTICAL INVESTIGATION OF THE SEISMIC PERFORMANCE OF MULTI-SPAN BRIDGES WITH STEEL PEDESTALS – ID 1497

*M. Hite, Georgia Tech, United States*
*R. Desroches, Georgia Tech, United States*
*R. Leon, Georgia Tech, United States*

Many bridges are damaged by over-height vehicles as a result of the vehicles impacting the girders of the bridge deck. To reduce the likelihood of impact from over-height vehicles, steel pedestals have been used as a cost-effective means to increase bridge clearance heights. Steel pedestals are short columns (typically 0.5 - 1.0 m in height) used to elevate and support the deck of a bridge and transfer the loads from the bridge deck to the columns and substructure. However, the steel pedestals installed on many bridges in the southeastern United States have been designed with no seismic consideration. To assess the seismic performance of steel pedestals on multi-span bridges, large-scale experimental studies have been conducted on 0.5 m and 0.85 m tall steel pedestals to define their behavior in a large-scale multi-span bridge model. A 2-dimensional analytical model of the bridge model is developed and subjected to a suite of ground motions to evaluate the performance of the steel pedestals and the overall bridge system. Detailed parametric studies are conducted on the bridge model to study the effect of varying levels of accelerations, elastic and inelastic bearing stiffness of the pedestals, and various relationships for the soil-foundation-pier bearing stiffness on the seismic performance of bridge steel pedestals. Results from the analytical investigation will show the most critical aspects that affect the performance of multi-span bridges with steel pedestals and provide the basis for recommendations on the design of the pedestals.

### CYCLIC RESPONSE OF EXISTING R.C. COLUMNS REPAIRED OR RETROFITTED BY MEANS OF FRP JACKETS – ID 2059

*T. Albanesi, University of Roma Tre, Italy*
*S. Santini, University of Roma Tre, Italy*
*C. Nuti, University of Roma Tre, Italy*

Seismic assessment of reinforced concrete structures as well as their rehabilitation and strengthening is dealt with in

many experimental and theoretical researches. New trends in seismic assessment essentially refer to "performance based design". Experimental research both on seismic assessment of existing elements as well as on the efficiency of different retrofitting techniques is essential. Cyclic tests on six circular columns already tested in previous experimental research [De Sortis et al. 1997], [De Sortis et al. 1998] and actually repaired and retested are presented. Tests aim to evaluate the effectiveness of retrofitting by FRP jackets not only to increase ductility but shear strength too. Columns have a circular section with a 400 mm diameter and two heights: 1.170 and 2.340 m. They have different longitudinal and transverse reinforcement being the result of two design criteria: one based on EC8 and the other on Italian Code before 1986. In the previous research columns were tested until collapse by pseudodynamic tests where they represented pier of irregular (the small columns) or regular (the tall columns) bridges. An accurate study to detect the level of degradation in materials, as the case of real structures after an earthquake, is performed. Then, based on the evaluation done, EC8 columns are repaired and the Italian ones retrofitted by mean of FRP jacket with the aim of enhancing ductility and shear capacity. Concrete at pier base, strongly cracked by previous tests, is repaired by resin injections and longitudinal bars are substituted whether failed before jacketing. Numerical analysis using fiber-beam elements, where a refined cyclic stress-strain model for rebar including buckling after yielding in compression and allowing the reproduction of very mild steel too is implemented, are carried out too. The model allows to simulate the cyclical degradation in terms of resistance of reinforced concrete elements.

## SC-A 0: Seismicity of the European-Mediterranean Area (Open Session – Posters Only)

Level 2

### MIGRATION OF EARTHQUAKES ALONG THE DEAD SEA TRANSFORM SYSTEM – ID 4

*T. Al-Yazjeen, Jordan Seismological Observatory, Jordan*

The Dead Sea Transform fault System is a well-defined tectonic feature extending for 1100 km along the west-northern borders of the Arabian plate. The space-time distribution of seismicity and faulting of this zone has been examined with a particular emphasis on the identification of possible seismic gaps. Results suggest several conclusions with respect to the temporal and spatial distribution of seismicity. First, the earthquake it occurs in cycles. Each cycle lasts for 380 years, and is divided into two periods, the first one include high seismic activity while the second one dose not include any strong earthquakes. Second, there appears to have been a two-directional migration of earthquake epicentres along the DST and to the east from a central region located at about 35.25°E longitude. The migration along the DST has a higher velocity than the migration to the east.

Key words: Earthquake prediction; Seismicity migration; Tectonics of Jordan.

Contact: t_yazjeen@yahoo.com

### SEISMOTECTONICS AND SEISMIC RELATED TO VARDAR VALLEY IN REPUBLIC OF MACEDONIA – ID 233

*B. Dimiskovska, IZIIS, Macedonia*

The investigations of seismicity, tectonics and geology of the territory of R. Macedonia have pointed out the direct relationship between the earthquake occurrence and the tectonic processes. To define seismogene foci and earthquake occurrence, it is necessary to know the geological evolution of the terrain, particularly in contemporary conditions. The earthquakes that occur in the investigated area are exclusively of a tectonic origin and the greatest attention is paid to the activity of the fault structures in the Vardar zone and the correlation between the epicentres of occurred earthquakes and the geological media through which the seismic waves propagate. From the seismotectonic map of the Vardar zone, it can be noticed that the stretching direction of the fault structures is in correlation with the epicentres of occurred earthquakes. The seismicity model formulated based on the seismological and seismotectonic investigations of the region has been the starting point in definition of the seismic hazard. A seismicity model to be used for definition of the seismic hazard according to the McGuire's method has also been defined. The comparison between these models will be discussed and a rationale on the seismic hazard of the Vardar zone will be given.

### SEISMIC ENERGY PATTERN OF ARMENIAN UPLAND – ID 298

*L. Sargsyan, National Survey for Seismic Protection in Armenia, Armenia*
*S. Margaryan, Armenia Association of Seismology and Phisics of t, Armenia*

Armenian Upland is one of the most active segments of Alpine-Himalayan seismic belt. The seismicity of Armenia and adjacent territories is related to the Arabian-Eurasian plate's collision. Seismicity of Armenian Upland and lesser Caucasus studied by number of researchers. An attempt to show the stress field changes in terms of energy before large and middle earthquakes is made. Detailed analysis of 42 year of seismic catalogue between 1962-2004 has been done. Armenian earthquake catalogue used for this study comprised of more than 6500 earthquake records with M≥2.5 in the area limited by 380 00'N to 420 00'N and 420 00'E to 480 00'N. It is demonstrated that this approach is applicable to area with hierarchic active block structure. The mapping in terms of energy is discussed, results show that before large and middle earthquakes energy pattern of investigated are undergo changes. Using moving-block method the energy distribution maps is compiled with step 1 year.

### SPATIAL AND TEMPORAL CHARACTERISTICS OF OCTOBER 2005, SIGACIK, AEGEAN REGION ACTIVITY – ID 317

*A. Berberoglu, Kandilli Obs.&ERI Bogazici Univ. NEMC, Turkey*
*N. Meral Ozel, Kandilli Obs.&ERI Bogazici Univ.Geophysics Dep, Turkey*

This presentation is concerned with the study of a three moderate size earthquake that occurred in Sigacik Gulf, Aegean Sea Coast and with their aftershocks. The big shocks (Ml=5.7, Ml=5.9, M=5.9) were located in the southern part of the Gulbahce fault. This fault zone is located along the N-S of Karaburun block and its length is about 15 km on land and comprises of strike-slip fault systems. This fault zone has been hypothesized that continues at the Aegean Sea bottom in the south and north of the Sigacik and Gulbahce gulf, respectively. According to the seismic reflection study; the total length of this fault zone is about 70 km (Ocakoglu et al 2005). Totally 4150 aftershocks (without threshold) occurred until 5 of Nov. by this activity. All the earthquakes (total 1230 ) that we have included in this study had magnitudes (Ml > 2.5), and 660 of them are magnitude greater than 3.0. We pay particular attention to locate the event and the events (M> 3.5) have been re-located using available data from the Greek islands, as well. The aftershocks extend mostly along east and west of big shocks as bilaterally, in a region of about 55 km long and 35 km wide. The zone aligned in the east direction is about 40 km in width and in the northwest direction over a length of about 55 km. On the other hand the distribution of aftershocks especially M>3.5 aligned NE-SW direction by including Greek stations. This intense activity, temporally, appears to decrease in time and frequency according to the laws known. Since Gulbahce fault consists of several sub branches, the occurrence pattern is different in timely and spatially. We calculated the b-value for this region by using all detected aftershock data set and found out the considerable value which the strike slip events are supposed to show.

### COMPOSITE FAULT PLANE SOLUTIONS FOR EARTHQUAKES IN REPUBLIC OF MOLDOVA – ID 369

*I. Sandu, IGG, Moldova, Republic Of*

We determine hypocenters and focal mechanisms of earthquakes on territory of Republic of Moldova using data from the Bulletins of International Seismological Center (ISC) and Moldova Seismic Network (MSN). Hypocenter relocation was carried out for the events which occurred in Moldova and for some events with initial location (ISC) close to territorial boarder of Republic of Moldova, from 1975 to 2005 that were reported by ISC and 4 stations from MSN. All of events are shallow earthquakes and with magnitude less than 4. For this set of earthquakes, we used both P and S arrival time data, because of small number of stations. Our relocation hypocenters result is resumed at 6 earthquakes inside of Moldova territory, 2 at North, 4 at South, and 4 more earthquakes closed to borders from Ukraine and Romania. For determination of focal mechanism of earthquakes in Moldova, we used the relocated hypocenters, and Composite P-first motion method. Focal mechanism on territory of Republic of Moldova is different from one to another area. We obtain focal mechanisms for 3 regions along the northen and the western border of country, which are in common with Romania, for North region – normal fault with EW T-axis direction, for Middle region – reverse fault with NS P-axis direction, for South region– strike slip fault with EW P –axis direction with reverse component. We suppose our results can be explained by the presence of the faults near to Dobrogea region, actually situated in Romania.

### SEISMOLOGICAL OBSERVATIONS IN THE NORTHERN PART OF MORAVIA, CZECH REPUBLIC – ID 484

*Z. Kalab, Institute of Geonics, Czech Republic*
*J. Knejzlik, Institute of Geonics, Czech Republic*
*J. Pazdirkova, Institute of Physics of the Earth, Czech Republic*
*P. Spacek, Institute of Physics of the Earth, Czech Republic*

National seismic station Ostrava-Krásné Pole (signed as OKC), seismic stations operated by the Institute of Physics of the Earth, Masaryk University Brno (IPE) and seismic stations operated by the Institute of Geonics of the ASCR Ostrava (IGN) monitor present natural seismicity. Seismic stations of IGN equipped with digital seismic recorder PCM3-EPC were installed on three places of the northern part of Moravia. These stations operated under triggered regime and were remotely controlled through a data transmission via a GSM network (their aim is detected events in the most active region). Five temporary stations with continuous recording are also operated by IGN from 2003. Seismic stations of IPE equipped by STS-2 and Quanterra or Guralp systems with continuous recording of data cover the whole region under discussion.

The Jeseníky area is characterized by an intensive neotectonic development of the old block stabilized by the Cadomian and Variscan orogens. This block underwent disintegration in the course of Alpine movements and during the Neogene and Quaternary, especially in contact areas with the Alpine orogenesis. Young tectonic and volcanic mobility caused a gradual tectonic regeneration of the Variscan platform along older faults, which is probably the main reason for recent seismic activity. In the last ten years this virtual joint network registered about 1.000 microearthquakes with maximum local magnitude up to 1.5. The seismic energy is often released in form of earthquake swarms. Earthquake foci recorded in 2003-2005 in Moravia and Silesia are displayed in sketchy geological map and this map documents weak recent natural seismic activity. Current resume of seismicity is possible to find in web sites of national seismological institutes (e.g., www.ig.cas.cz, www.ipe.muni.cz).

### THE AZIMUTH DEPENDENT ATTENUATION COEFFICIENTS AND QS FOR THE TERRITORY OF REPUBLIC MACEDONIA – ID 495

*P. Lazo, Seismological Observatory, Macedonia*

Dynamic characteristics of the seismic waves and the spatial distribution of the macroseismic data, as a function of epicentral distance, include influence of the terrain topography, local site effects, tectonics characteristics and the focal mechanisms.

In first step, three terms intensity attenuation relations to all azimuths beside the hypocentral distance has been calculated based on selected empirical isoseismal maps for the earthquakes with Imax$\geq$VIII MCS (1904-1990), which were digitized by using a special extrapolating-smoothing procedure. The results are maps of spatial distributions of the values of the attenuating coefficients.

In the second step, propagation of the seismic waves for selected azimuthal directions has been investigated. The input data was measured on the seismograms of selected earthquakes with epicenters on the territory of the R. Macedonia and its neighboring seismic active areas. The Q values for selected directions of seismic wave-path propagation were calculated by using the Amax maximum wave-amplitude-attenuation relation. The QS values were estimated from the attenuation of the Sg and Lg waves, recorded on the seismographs installed at the Seismological Observatory in Skopje (SKO) and seismological stations in Ohrid (OHR) and Valandovo (VAY). The final values of QS were calculated for three predominant directives.

The final results are: intensity attenuation of the strongest earthquakes in the epicentral areas is characterized with particular azimuthal-attenuation-coefficients-relations. The Amax attenuation has shown an azimuthal dependence; smaller along the tectonic structures in the Vardar-seismogenic zone (along the direction SKO-VAY) are greater than those for the directions SKO-OHR and OHR-VAY. The correlation results between azimuthal depended macroseismic attenuation coefficients and QS values are going to be presented.

### INSTALLATION AND FIRST RESULTS OF A PERMANENT OCEAN BOTTOM SEISMOMETER OFFSHORE TARRAGONA (NE SPAIN) – ID 546

*T. Frontera, Institut Cartogràfic de Catalunya, Spain*
*J. Jara, RSE S.A. Aplicaciones Territoriales, Spain*
*X. Goula, Institut Cartogràfic de Catalunya, Spain*
*A. Ugalde, Observatori de l'Ebre, Spain*
*C. Olivera, Institut Cartogràfic de Catalunya, Spain*

The Institut Cartogràfic de Catalunya (ICC) and the Observatori de l'Ebre, in collaboration with the Spanish oil company Repsol Investigaciones Petrolíferas, are carrying out a project with the aim of improving the knowledge of the seismicity and seismic risk in the Tarragona region (northeastern Spain). Within this framework, on August 2005 a permanent ocean bottom seismometer (OBS) was installed inside the security perimeter of the Casablanca oil platform, which is located 40 km offshore Tarragona. This pioneering project in Spain is being financed by the Ministerio de Educación y Ciencia (CASABLANCA REN2003-06577), FEDER funding and the ICC. The OBS station has a three component broad band sensor and a differential pressure gauge. They were submerged at about 400 m to the SW of the oil platform and were deposited at about 150 m depth. Data are digitized on-site and are transmitted through a submarine cable to the platform, where they are recorded. A continuous mode and almost real time VSAT satellite data transmission from the platform to the data center at the ICC is expected for 2006. This step will imply the total integration of the OBS station into the ICC seismic network. Since the OBS is operative, some local as well as distant seismic events have been recorded. A seismic noise study from the OBS and the differential pressure gauge recordings has also been performed.

### THE OBS FORMAR NETWORK – ID 685

*J. M. Davila, Real Observatorio de la Armada, Spain*
*A. Pazos, Real Observatorio de la Armada, Spain*
*E. Buforn, UCM, Spain*
*A. Udías, UCM, Spain*
*W. Hanka, GFZ, Germany*

The Eurasian-African plate boundary crosses the so called "Ibero-Maghrebian" region from Gloria fault to Tunisia in a more or less West-East direction. The low convergence at this boundary line, producing a moderate seismic activity of low magnitude and shallow depth earthquakes, some intermediate depth shocks and very deep earthquakes, with sporadic large events. To study this complex area the Royal Naval Observatory in San Fernando (ROA) and the University Complutense of Madrid (UCM) together with the GeoForschungZentrum of Potsdam (GFZ) have deployed the Western Mediterranean BB network (WM) with stations located in southern Spain and Northern Africa, mainly surrounding the Alboran sea. Due to the fact that many events are located at marine areas, land stations lacked sufficient coverage of marine areas. To solve this problem the WM network will be complemented with a deployment of Ocean Bottom Seismometers (OBS) in the Cádiz Gulf and the Alborán sea. The Spanish Research Council (Ministerio de Educación y Ciencia) has funded 4 OBS deployments through the projects: RIOA05-23-002 (OBS Alborán) and CGL2005-24194-E (Red FOMAR). The OBS will be deployed with the support of the Spanish Navy ships and will start within 2006 and includes a permanent OBS at Mid Alboran Sea, which will remain deployed for at least a three years period. Some of them will be finally converted to permanent devices. In this paper we describe the present status of the OBS deployment, and the future planned steps, in the frame of the Western Mediterranean (WM) network activities.

## ENVIRONMENTAL CARTOGRAPHIC MODELS FOR THE REGION OF VARNA PALEOSEISMIC PHENOMENA (BULGARIA) – ID 763

*D. Angelova, Bulgarian Academy of Sciences, Bulgaria*

The Varna paleoseismic phenomena marked the epicentral part of the catastrophic earthquake. The time of its origin was probably during the great Chaudian transgression since all the changes in the sea level occurring before it had been preserved in the cliff. The documented historic earthquakes of the Ic B.C. and XVc provoked some important corrections in the type of the relief in the city of Varna, considerable destructions in the highway netin the littoral zone between the city of Varna and cap of Galata et al., also human casualties. The effects had a faults and landslide predestination. Later, the Shabla 1901 earthquakes with M=7.2, I=IX-X mobilized faults, landslides and rock falls in the region. They were repeativated by the earthquakes in 1444, 1858, 1891, 1901, 1902, 1903. The strong and relatively deep earthquakes of the Vrancea, Black Sea, Crimea, Caucasus, Asia Minor and Mediterranean cause creating local and regional activity of the investigated area. The local and regional development of the abrasion, limans, marshes, landslides, rock falls and suffusion effects produces an important influence to the relief evolution of the littoral and sometimes the anthropogenic factors from other side, cause the reactivation and new formation of the fractures and faults. The present work shows also the geoecological assessment of the contemporary natural hazards. For the study purposes are prepared different types of maps (shown on the specific maps applied) of 25,000 scale, which served for the qualitative and assessment of natural and anthropogenic hazards.

## IMPROVED EARTHQUAKE LOCATIONS IN GREECE USING THE DD ALGORITHM AND A 3D VELOCITY MODEL – ID 810

*O. Galanis, Aristotle University of Thessaloniki, Greece*
*C. Papazachos, Aristotle University of Thessaloniki, Greece*
*E. Scordilis, Aristotle University of Thessaloniki, Greece*
*P. Chatzidimitriou, Aristotle University of Thessaloniki, Greece*

Accurate earthquake locations are necessary for seismicity, seismic hazard, seismotectonics, seismic tomography and other basic research and applications. As the existing catalogs are not, in most cases, accurate enough, they must be revised using more advanced earthquake location algorithms such as the double-difference (DD) earthquake location algorithm. We located 100000 earthquakes which occurred in Greece and the surrounding areas (33-43N, 18-30E) during a period of 23 years (1981-2003). The data used was a list of P and S wave arrival picks compiled by combining data from the archives of a regional seismic network operating since 1981, from phase picks contributed to the International Seismological Center by neighboring networks, as well as data from temporary local networks. The earthquake hypocenters were relocated using the Double-Difference earthquake location algorithm whenever this was possible. The original, freely distributed implementation of the algorithm (Waldhauser 2001) was altered, in order to use a three-dimensional seismic wave velocity model of the area which has been determined by earlier tomographic studies. When double-difference location was not possible because the event is spatially isolated or the pick errors are too high, the events were located with the conventional absolute location method (Geiger's method). The resulting earthquake catalog consists of events divided into two categories, according to the method used for the location (double difference location or absolute location). The new catalog, especially the double-difference located part, reveals seismicity patterns otherwise invisible or blurred by the absolute location errors.

## EMSC REAL TIME EARTHQUAKE INFORMATION SERVICES – ID 885

*G. Mazet-Roux, EMSC, France*
*S. Godey, EMSC, France*
*R. Bossu, EMSC, France*

EMSC operates a web-based Real Time Earthquake Information (RTEI) service, also available in IMODE, WAP and soon in RSS, which aims at providing rapid and reliable information for the Euro-Med earthquakes and for large global ones. This service is based on parametric data provided by 57 seismic networks automatically processed at EMSC. EMSC manually reviews within less than 60 minutes (alert system) the location of potentially damaging Euro-Med events and large global ones, and on the following working day for the other events. In 2005, more then 10,000 events have been published on the RTEI page (http://www.emsc-csem.org).

In the framework of the alert system, the locations are disseminated by fax, email and SMS to more than 6,300 end-users. The alert system is operated in collaboration with the LDG (EMSC host institute) and the IGN (Madrid) which runs back-up procedures and takes over the duty whenever it is required. The earthquake notification service has been upgraded in 2006. Each user can now define an area and a minimum magnitude of interest and the messages are distributed in 4 different formats.

The way the RTEI services works and the performances of the whole system in terms of location accuracy and time performances will be presented here. We will also show how this system allows filtering potentially erroneous automatic solutions and also rapidly publishing preliminary information for all significant Euro-Med events (11 minutes after the earthquake occurrence on average).

We will also present the Euro-Med Bulletin which aims at producing a comprehensive bulletin since 1998 at the Euro-Med scale using the parametric data collected from 64 local agencies.

## FRACTAL BEHAVIOUR OF AFTERSHOCKS OF AL-HOCEIMA EARTHQUAKE OF 24 FEBRUARY 2004 (MOROCCO) – ID 1007

*M. Rouai, Earth Sciences Department, Meknes University., Morocco*

Al Hoceima region (northern Morocco) was struck by an important earthquake (M 6.1) on February 24, 2004; inducing a devastating damage and 629 victims. The aftershocks sequence following the main event (522 events with M$\geq$3 during 17 days) has been investigated by non-linear tools. The inter-event time between successive aftershocks is analyzed to study the temporal fractal structure and clustering properties by means of: Omori and Korçak laws, Hurst analysis, fractal correlation dimension, autocorrelation function and coefficient of variation, etc. From the Gutenberg-Richter law, the b value is found to be close to 1. The Omori law exponent is near 1.1. Fractal temporal correlation dimension is around 0.9, indicating a continuous and nearly uniform

aftershock activity during this period, that is confirmed by the auto-correlation analysis and a high persistence behaviour from the Hurst analysis (H 0.75). Investigating the aftershocks time structure, a moving window of 100 events shifted by 10 was used to follow the temporal variation of the Hurst exponent ($0.64 \leq H \leq 0.84$) and the statistical coefficient variation ($0.86 \leq cv \leq 1.20$) within the whole sequence. The results show a rather uniform persistence of inter-event times despite a low decrease of randomness degree indicated by cv fluctuation. The temporal organization of the analyzed aftershocks sequence obeys power-law behaviour (scale-invariance), with high degree of persistence and uniformity (high correlation of inter-event times and low clustering). This may put light on the rupture and fault geometry and characterize the underlying pattern seismicity in the region.

## ANALYSIS OF THE 09/2004 SEISMIC CRISIS IN THE AREA OF THE 1428 EARTHQ. (I0=IX), EASTERN PYRENEES. – ID 1034

*S. Figueras, Institut Cartogràfic de Catalunya, Spain*
*A. Villaseñor, Inst. de Ciències de la Terra "Jaume Almera", Spain*
*T. Frontera, Institut Cartogràfic de Catalunya, Spain*
*C. Olivera, Institut Cartogràfic de Catalunya, Spain*
*J. Fleta, Institut Cartogràfic de Catalunya, Spain*
*M. Ruiz, Inst. de Ciències de la Terra "Jaume Almera", Spain*
*J. Díaz, Inst. de Ciències de la Terra "Jaume Almera", Spain*
*J. Gallart, Inst. de Ciències de la Terra "Jaume Almera", Spain*
*J. Vergès, Inst. de Ciències de la Terra "Jaume Almera", Spain*

In the Eastern Pyrenees, at the same area of the 1428 destructive earthquake (Io=IX, EMS-98), a Ml=4.0 earthquake took place on September 21st 2004. It was widely felt in the region and produced slight damage at the epicentral zone. This area is characterized by a continued moderate seismicity, with a few events of magnitude close to 4 reported in the last decades. For this most recent event the hypocentral localisation from the permanent seismological regional network of the Institut Cartogràfic de Catalunya (ICC) is 42.34° N, 2.17° E and 4 km depth. The focal mechanism calculated from first-motion data of 35 stations shows a dextral strike-slip movement with a normal component. According to the dominant EW geological structures in the epicentral area, a nearly EW oriented nodal plane would be considered as the fault plane, the NW-SE orientation of the pressure axis is coherent with the regional axis direction. In the following two days the permanent network registered about 120 aftershocks, three of which were felt again in the epicentral zone.

A temporary network of 6 portable three-component stations were installed during 35 days in the epicentral area. The network operated in continuous mode and allowed detection and location of about 800 aftershocks with magnitudes lower than Ml=2.0. The earthquakes have been located first with the Hypo71 code. A reevaluation of the hypocentral parameters with a probabilistic, non-linear global search earthquake location in 3D structures method have been conducted and the selected earthquakes have been relocated using the double difference location method HYPODD code considering ordinary absolute travel time measurements and cross-correlation wave differential travel-time measurements.

The temporal monitoring by portable seismic stations after a relevant earthquake and the analysis of the aftershocks provides a better knowledge of the local seismotectonic features.

## A NEW TELEMETRY SEISMOLOGICAL NETWORK IN THE FRONT PART OF THE HELLENIC ARC – ID 1050

*F. Vallianatos, TEI CRETE, Greece*
*J. Makris, TEI CRETE, Greece*
*P. Soupios, TEI CRETE, Greece*
*V. Saltas, TEI CRETE, Greece*
*G. Hloupis, TEI CRETE, Greece*
*I. Nikolintaga, TEI CRETE, Greece*
*E. Kokkinou, TEI CRETE, Greece*
*I. Papadopoulos, TEI CRETE, Greece*
*M. Moisidi, TEI CRETE, Greece*
*D. Kalisperi, TEI CRETE, Greece*

A new telemetric seismic network has been installed on the island of Crete and the broader area of South Aegean and is continuously operated by the Laboratory of Geophysics and Seismology (GSL) of the Technological Educational Institute of Crete in order to provide modern instrumental coverage of seismicity in the southern Greece, as well as some more insight into the stress and deformation fields, tectonics, structure and dynamics of the Hellenic Arc. The latter is the seismically most active region in western Eurasia due to subduction of the oceanic African lithosphere beneath the lithosphere of South Aegean. The network is currently comprised of twelve short period stations and one broad-band station, equipped of three-component sensors, third generation high resolution 24-bits digitizers, Reftek type 130-1. Telemetry is digital in terms of conventional TCP/IP networking using dedicated ADSL-VPN connections. Data are transmitted to the central processing unit, situated at the GSL building in Chania, Crete. Data packets are stored in two data servers and one real time processing server running Seismic Network Data Processor (SNDP) software. Network's geometry as well as site selection has been chosen carefully, since the primary goal is to locate seismic events, fact which assures the most accurate determination of seismic parameters. Furthermore, plenty of studies are conducted, concerning mainly the crust structure of the area which will lead to a representative velocity model, the stress-field and the focal depth distribution. The first results from the operation of this permanent network are presented and special attention is given on the January 8, 2006 Kythira intermediate depth earthquake, with M=6.9 located at 36,21°N - 23,34°E.

This work is supported by the project ARCHIMEDES I: "Support of Research Teams of T.E.I Crete", sub-project entitled "Multidisciplinary Seismic Hazard monitoring in the Front of the Hellenic Arc.

## PRELIMINARY RESULTS OF THE KYTHIRA JANUARY 8, 2006 AFTERSHOCK SEQUENCE – ID 1063

*F. Vallianatos, TEI CRETE, Greece*
*I. Nikoolintaga, TEI CRETE, Greece*
*E. Kokkinou, TEI CRETE, Greece*
*J. Makris, TEI CRETE, Greece*
*P. Soupios, TEI CRETE, Greece*
*M. Moisidi, TEI CRETE, Greece*

On January 08, 2006 at 11:34:53 (UTC) a strong earthquake of magnitude M=6.9 shook Greece and most of the eastern Mediterranean causing only minor damages and no casualties. The earthquake's epicenter was located at 36, 21°N - 23, 34°E at a depth of about 70 Km near the island of Kythira. The main shock as well as the aftershocks were recorded by the stations of the seismological network of the Laboratory of Geophysics and Seismology of the Technological and Educational Institute of Crete in Chania which is the closest seismological observatory in southern Aegean, about 90 Km SE of the epicenter. The network has recorded the aftershock sequence in the broader area with magnitudes up to about 5.0 on the Richter scale. The evolution of the earthquake sequence is studied and data are analyzed. Analyses include the relocation of the aftershocks and proposal of a new 1D model of the earth structure of the southwestern part of the Hellenic Arc. The aforementioned implementations will help us elucidate more the seismic behavior of the broader area which seismically is one of the most active parts of the Western Eurasia due to the subduction of the African lithosphere under the Aegean microplate and has a long historical record of devastating earthquakes with magnitudes up to about 8.0.

This work is supported by the project ARCHIMEDES I: "Support of Research Teams of Technological Educational Institute of Crete", sub-project entitled "Multidisciplinary Seismic Hazard monitoring in the Front of the Hellenic Arc " in the framework of the Operational Programme for Education and Initial Vocational Training.

### THE SURPRISING KALININGRAD EARTHQUAKES OF SEPTEMBER 21, 2004 – ID 1254

*P. Wiejacz, Inst of Geophysics PAS, Poland*

The earthquakes of magnitudes mb 4.4 and 5.0 in the Kaliningrad enclave of Russia on September 21, 2004 were unexpected in a very low-seismicity area. The earthquakes caused minor damage in the Kaliningrad enclave, in northern Poland and in southwestern Lithuania, and macroseismic observations imply maximum intensities of 6-7 (EMS) close to the epicenters. The larger earthquake was felt at distances of up to 800 km. The events have been located at a 16 and 20 km depth under the central-northern part of the Sambia Penninsula and their source mechanism has been found to be a right lateral strike slip on a direction parallel to the edge of the Fennoscandian Shield and the East European Craton. While the possible cause of the earthquakes is being discussed, historical information seems to evidence past seismic activity in the region, which together with the 2004 earthquakes warrant the reassessment of the seismic hazard in the area.

### EARTHQUAKE SWARM AT THE NORTHERN PART OF THE RED SEA, EGYPT. – ID 1317

*S. Salah El-Hadidy Youssef, national research institiute of astronomy and geop, Egypt*

The Northern Red Sea-Gulf of Suez Trend is considered as one of the active seismic sources in Egypt. On 21 August 2001 an earthquake swarm has been recorded by the Egyptian National Seismic Network (ENSN). This activity started from August to September 2001. The total number of recorded earthquakes is 800 events without any distinguish events. The space -time distribution of the recorded events were studied. The focal mechanism solutions of the two largest earthquakes show normal faulting with strike slip component. Three seismic stations situated at three different localities were selected to study the propagation path and site effects on the waveforms and frequency contents of the recorded events. Seismogram interpretations of the recorded events reflect a very week arrivals with low amplitude followed by sharp reflected phase after 1.5 seconds at the stations located at entrance of the Gulf of Suez to the northeast and northwest of the epicenter, this phase disappears in the station located at the southwest of the epicenter. There are two different event groups, each group has similar waveforms. The similarity of waveforms increases with decreasing of frequency. This feature suggests that the earthquakes of this event pair repeatedly on the same fault plan. The disagreement in high frequencies may be due to detailed differences in the rupture process at the source. The frequency range having similar waveforms depends on the earthquake size. The existence of event groups with similar waveforms is one of most important features of earthquake swarms. The complexity and heterogeneities of the earth's structure causes the seismogram of such a great variety of waveforms and wave types. The waveforms in the seismograms, especially the appearance of phases differs with the propagation path even in the events with similar epicentral distance, source depth and earthquake size.

### IMPROVEMENTS OF SEISMOGENIC FAULT DETECTION IN SOUTHERN ITALY BY APPLICATION OF NON-LINEAR EARTHQUAKE LOCATION METHODS – ID 1561

*D. Presti, Dipartimento di Scienze della Terra, Messina Unive, Italy*

Seismicity occurring in the last few decades in and around Sicily has been investigated with the purpose of accurately identifying the location and geometry of the main seismogenic fault systems in this portion of the Nubia-Europe contact belt. The prevailing off-shore location of the main faults (capable of generating M7-class earthquakes) has, in the past years, made the data acquisition slow and the definition of geophysical and geological features of these structures quite problematic. Hypocenter locations have been performed using an earthquake dataset (1978-2005) obtained by integrating the national and local network databases, and a three-dimensional seismic velocity model recently computed for the study region (Barberi et al., PEPI, 2004). Clear improvement in the knowledge of fault geometries in the study region has been proven to come from application of the Bayesian location method, Bayloc, proposed by Presti et al. (BSSA) 2004. Bayloc properties of accounting for non-linearity of the location process and plotting epicenter maps as cumulative probability distributions (where individual earthquakes are weighed according to location accuracy) played a major role in compensating the main defaults of linearized algorithms. A wide series of synthetic location tests was also performed and allowed us to better define to what extent real earthquake locations were influenced by network geometry over the study region during the investigation time interval. In particular, relocation of synthetic events clarified whether hypocenter trends found by investigating the real seismicity are faithful markers of seismogenic structures or if they represent fictitious products of poor network geometry. The results have been evaluated in the light of the geophysical and geological information available in the literature for the study region.

### GOKOVA (TURKEY) EARTHQUAKES AND SOME CONSEQUENCES – ID 1572

*O. Gundogdu, Istanbul University, Turkey*
*H. Alp, Istanbul University, Turkey*
*S. Karabulut, Istanbul University, Turkey*
*S. Ozcelik, Istanbul University, Turkey*

In Gokova Bay and surrounding area , tree earthquakes (M=3,5 dated 2 August 2004; M= 5.0 dated 3 August 2004 and M =5.4 dated 4 August 2004) occurred in the north of Datça (KOERI Data). Gökova region was defined as a small plain that occurred due to the tectonic forces that have been acted since middle Pliocene. Tectonic and geomorphologic properties of this region were described by Kayan (1972). In this work, it was explained the complex tectonic structure that presents the E-W trending graben system. This earthquake activity has been continued by the decreasing rates. For the macro-seismic studies, we, as a Earthquake Research Group of Department of Geophysical Engineering of Istanbul University, were investigated the region by the field studies and were prepared the isoseist map (Maximum intensity as Io=VI). Source mechanism of the earthquake (M=5.4) were determined as a normal faulting with minor strike slip component. . When we consider the moderate earthquakes in Turkey caused important structural damages, For this region, the structures must seriously be controlled. In this region there are tree thermic power plant. This is a risk for this region. To trace the earthquake activity by local seismic network, will provide the detailed information on tectonic structure and geodynamic forces in the region.

### SEISMICITY OF THE TERRITORY OF TOKTOGUL RESERVOIR FOR A PERIOD OF 1991-2001. – ID 1593

*K. Murataly, Seismology, Kyrgyzstan*
*E. Kulia, Seismology, Kyrgyzstan*

The aim of the given paper is variation determination of seismicity for the region of Naryn of cascade Hydro Power Stations (HPS) according to the latest data for a period of 1991-2001. Therefore it is necessary to solve such problems as creation of map-scheme of seismicity variation for the territory of Naryn region for observed periods of time, map-scheme of earthquakes epicenters allocation for the studied lease of certain period of time. In the territory of the studied region there's regional Talas Fergana fault and forking tectonic faults. It, as a matter of fact, has stipulated rather high seismicity of the region for building, estimated possibility seismic intensity of 9 on MSK-64 earthquakes. For all period of observations in Toktogul region there were no sharp changes in their customary location by square. Only in definite periods of time, bound with leaps of water line in the reservoir, discrepancies in their allocation took place. Data analysis, presented in work, shows that seismicity in the territory of the studied lease of Naryn HPS stage in the considered period of time, basically, is stable: the amount of recorded seismic events does not

exceed in many years 60-70 earthquakes annually. The deflection from the medium amount of earthquakes was noted only in August 1992, time of known Suusamyr earthquake with M=7.3.

### STUDY OF THE MALAGA (SPAIN) SEISMICITY FROM HISTORICAL AND INSTRUMENTAL DATA – ID 1603

*T. Goded, Universidad Complutense de Madrid. Facultad Fisica, Spain*
*E. Buforn, Universidad Complutense de Madrid. Facultad Fisica, Spain*
*D. Muñoz, Universidad Complutense de Madrid. Facultad Fisica, Spain*

The Malaga region is located in the Betics (South Spain) and it is characterized by the occurrence of moderate to large earthquakes at shallow (h<30 km) and intermediate depth (30<h<150 km). In the past, two earthquakes with EMS-98 intensities equal or greater than VIII affected seriously the city of Malaga: the 1/26/1494 and 10/9/1680 earthquakes. New intensity maps have been obtained for both shocks using new information found in archives, libraries, etc. The results show that the 1494 earthquake had a maximum intensity of VIII (EMS-98) in Malaga city, and was also felt in other towns such as Granada or Seville. The coastal region was the most affected, with a distribution of damages in an East-West direction. The 1680 earthquake had a maximum intensity of VIII-IX (EMS-98) in Malaga and the towns located at the West. The earthquake also affected other towns such as Cordoba, Seville or Cadiz, and cities at further distances such as Madrid and Valladolid. The distribution of damages follows a North-South direction. A thorough investigation has been made on the damages caused to individual buildings of the city, especially in the case of the 1680 earthquake. These results will be applied to vulnerability studies of the monumental buildings in Malaga. Small earthquakes occurred at shallow and intermediate depth have been used as empirical Green functions to obtain synthetic accelerograms of earthquakes with a range of magnitudes 5.0-6.5. These results will be used to compare the damages degree caused by the 1494 and 1680 events on the monumental buildings with the values obtained for the synthetic events. The comparison is focused on the maintenance of these buildings that could be seriously damaged if important earthquakes such as the 1494 and 1680 ones ever occur.

### EMPIRICAL EARTHQUAKE RECURRENCE LAWS IN CROATIA ESTIMATED BY FORWARD MODELING – ID 1643

*M. Herak, Faculty of Science, Croatia (Local Name: Hrvatska)*
*D. Herak, Faculty of Science, Croatia (Local Name: Hrvatska)*

A method to account for intrinsic aleatory variability of parameters controlling earthquake recurrence is presented. Dropping the assumption of time-invariable coefficients, the number of parameters increases from 4 (in the modified Gutenberg-Richter relation) to 10 or more. Inverse problem of finding the values of representative recurrence parameters is solved by forward modeling which generates probabilities that competing sets of parameters adequately describe the observed seismicity. The method is applied to four seismically active areas in Croatia, yielding probabilities for a large number of possible recurrence laws to adequately describe observed seismicity.

### REVISION OF LOCAL MAGNITUDES REPORTED IN THE CROATIAN EARTHQUAKE CATALOGUE FOR THE PERIOD 1908-1999 – ID 1656

*S. Markusic, Faculty of Science, Croatia (Local Name: Hrvatska)*
*I. Ivancic, Faculty of Science, Croatia (Local Name: Hrvatska)*
*I. Allegretti, Faculty of Science, Croatia (Local Name: Hrvatska)*
*D. Herak, Faculty of Science, Croatia (Local Name: Hrvatska)*
*M. Herak, Faculty of Science, Croatia (Local Name: Hrvatska)*

Croatian Earthquake Catalogue (CEC) contains basic information for over 25000 earthquakes that occurred in Croatia and in the neighbouring territories in the period 373 BC–2006. The instrumental part of the catalogue starts in 1908 when the first Wiechert seismograph was installed in Zagreb (ZAG) by A. Mohorovicic. All seismograms are stored and kept in the archives of the Department of Geophysics, along with notebooks containing calibration data. Mechanical Wiechert seismographs were the official ones until replaced with electromagnetic instruments in the early 1980-ies. Digital BB seismographs were installed in the year 2000. As ZAG is the only station in Croatia that has been continuously operating for the last 100 years, the ZAG local magnitude, M(ZAG), is reported in CEC for each event, along with the magnitude taken from various catalogues, bulletins, reports, etc. M(ZAG) is determined from ZAG records using local calibration function initially derived by D. Skoko (1969) on the basis of Wiechert seismograms. The same relation was also routinely used after switching to electromagnetic seismographs (Sprengnether), as well as after the station was moved to a new location. Recent investigations reveal that M(ZAG) shows significant discrepancies from medians of magnitudes reported by other seismological institutions, especially at short epicentral distances, thus rendering CEC nonuniform and non-homogeneous with respect to magnitude. As CEC is the basic tool for seismic hazard analyses in Croatia it seems imperative to recalibrate ZAG magnitudes of the pre-digital era against a representative sample of magnitude estimates from European stations, as reported in the ISC and other available databases. Here we present results of regressions used to derive new local magnitude formulas, separately for Wiechert (1908-1982) and Sprengnether (1983-1999) seismographs. We also analyse the completeness and homogeneity of the revised catalogue, as well as the Gutenberg-Richter frequency-magnitude relation for the selected subcatalogues.

### PODHALE, POLAND, EARTHQUAKE OF NOVEMBER 30, 2004 – ID 1678

*W. Debski, Inst. of Geophysics PAS, Poland*
*B. Domanski, Inst. of Geophysics PAS, Poland*
*P. Wiejacz, Inst. of Geophysics PAS, Poland*
*A. Zych, Inst. of Geophysics PAS, Poland*

Earthquake of November 30, 2004 in Podhale region, southern Poland took place shortly after the September 21, 2004 events of Kaliningrad Region, Russia, that inflicted minor damage in northern Poland. Therefore the Podhale quake has caused concern about seismic hazard in Poland which is understood a country of low seismicity. Although not so much unexpected as the earthquakes in the north, the quake was of unexpected size as according to some determinations it reached magnitude 4.7 with macroseismic intensities up to 7. The event was felt to distance of about 100 km and inflicted slight damage to buildings in its narrow epicentral area, thus evidencing its relatively shallow depth. The quake has been located near the village of Skrzypne, about 15 km west-southwest of the district capital Nowy Targ. The source mechanism has been found to be of dip slip normal fault type, although it remains a problem of association this mechanism with known tectonic dislocations in the region. The earthquake has been followed by a long series of aftershocks. Their distribution in time is also studied and the biggest aftershocks have been located.

### SEISMICITY OF THE RUSSIAN PLATFORM FROM "MICHNEVO" SMALL-APERTURE ARRAY DATA – ID 1725

*I. Sanina, Institute of Geospheres Dynamics, Russian Federation*
*S. Volosov, Institute of Geospheres Dynamics, Russian Federation*
*N. Gamburtzeva, Institute of Geospheres Dynamics, Russian Federation*
*Y. Schukin, Institute of Geospheres Dynamics, Russian Federation*
*M. Nesterkina, Institute of Geospheres Dynamics, Russian Federation*
*O. Chernyh, Institute of Geospheres Dynamics, Russian Federation*
*O. Riznichenko, Institute of Physics of the Earth, Russian Federation*

Small aperture seismic array is operating on the territory

of the geophysical observatory "Michnevo",Moscow region, since November, 2004. The array consists of 16 short-period seismic sensors SM3-KV with frequency band 0.5-40 Hz. At present about 2000 seismic events of different origin were recorded by the array. Beside teleseismic events, most recorded signals are quarry blasts from epicentral distances up to 700 km. Identification of small earthquakes from quarry blasts is one of the main tasks of the array. There is an evidence of paleoseismic events on the Russian platform, specifically for the Voronezh crystalline massive, but no detailed study of regional seismicity has been carried out so far. Since there are no criteria of identification of seismic events of different origin for the Russian platform, we applied criteria, developed earlier for the territory of Kazakhstan and Kyrgizia. In Kyrgizia criteria were specially worked out for the recognition of the chemical explosions. About 200 events were analyzed, and 29 were selected with distinct P, S and Lg arrivals. Analysis of spectral properties of waves of different types and their amplitude ratios was performed. As a result, we identified 20 explosions, 2 earthquakes and 7 events with no reliable estimates. The earthquakes are: November 11, 2005, t=10h 01m 44.7 s with coordinates (51 grad 10'8"N, 36 grad 41'40"E ) and magnitude 1.7, and January 24, 2006, t=12h 14m 33.9 s with coordinates (52 grad 59'N, 39 grad 06'E) and magnitude 2.6. Both events are located in the region of the Voronezh crystalline massive, characterized by past and present seismic activity.

## SEISMIC ACTIVITY OF THE ALPINE-CARPATHIAN-BOHEMIAN MASSIF CONTACT REGION AND ITS GEOPHYSICAL PATTERN – ID 1728

*J. Pazdirkova, Institute of Physics of the Earth (IPE) MU, Czech Republic*
*W. A. Lenhardt, Central Institute for Meteorology and Geodynamics, Austria*
*J. Svancara, IPE, Czech Republic*
*J. Havir, IPE, Czech Republic*

The seismicity of the contact of the Eastern Alps, the Western Carpathians and the Bohemian Massif was investigated within the frame of a joint project of ZAMG Vienna and IPE Brno. New seismological stations were built in the area of interest (47.5°N to 49.8°N, 13.0°E to 19.0°E) with real-time data transmission to both institutions. The location accuracy of earthquakes in this region was significantly improved. Eleven earthquake catalogues were evaluated and checked for multiple entries and mistakes elimination. The final data set of earthquakes covers the time span from 1267 to 2004 and comprises 1968 earthquakes in total. The resulting epicentral map provides a very detailed idea about the seismicity of this region. An attempt to a seismo-tectonic interpretation of earthquakes based on the geological overview of the region is presented. Geophysical data in addition to seismic events were collected and cross-border maps were compiled and analysed. Regional geophysical data from gravity and airborne magnetometry survey were selected for the analysis of the subsurface extent of geological bodies with contrasting petrophysical properties. The colour shaded relief maps were used to delineate pronounced lineaments whereas the Linsser method was applied to analyse the density contacts at two potentially seismogenic depth horizons. This data set enabled to determine seismically active fault structures and to get an insight into the fault system interaction. Ability to assess vertical and horizontal extent of fault structures potentially seismically active will enable to improve hazard assessments in future.

## MOMENT MAGNITUDE AND DURATION MAGNITUDE DETERMINATION IN CENTRAL GREECE – ID 1739

*G. Kaviris, University of Athens, Greece*
*P. Papadimitriou, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*

The Gulf of Corinth is considered to be one of the most active tectonic rifts around the world, producing one of the highest seismic activities in the Mediterranean region. In 1995 the Seismological Laboratory of the University of Athens installed the telemetric Cornet network around the Eastern Gulf of Corinth. A velocity model consisting of six seismic layers was calculated, while the majority of the local events were located within the Gulf of Corinth. The main scope of the present study is the determination of a reliable earthquake magnitude. Concerning the rapid calculation of the duration magnitude Md, a multiple linear regression technique was developed for the determination of the constants a, b and c. As a result the formula Md = -1.1 + 2.35 logD + 0.0012 d was obtained. The satisfactory precision by which the constants a, b and c were calculated, ensures that the duration magnitude Md obtained by the Cornet network is reliable. Following, the moment magnitude Mw, which is considered to be the most reliable magnitude scale, was also determined. Spectral analysis was applied for the calculation of the seismic moment M0 and a seismic catalogue was created, where the moment magnitude Mw is directly calculated by processing digital data. After the determination of the moment magnitude Mw and of the duration magnitude Md, a relationship between them was obtained, using the least-squares method. Relationships between these magnitudes, the local magnitude ML, the body wave magnitude mb, calculated by the ISC, and the seismic energy were also obtained. ACKNOWLEDGMENTS The present study was funded through the program EPEAEK II in the framework of the project "Pythagoras - Support of University Research Groups" with 75% from European Social Funds and 25% from National Funds", contract No. 70/3/7306.

## THE BORMIO EARTHQUAKE SEQUENCES OF DECEMBER1999-JUNE 2002 – ID 1743

*A. Zappone, Swiss Seismological Service, Switzerland*
*N. Deichmann, Swiss Seismological Service, Switzerland*
*J. Braunmiller, Swiss Seismological Service, Switzerland*
*R. Di Giovambattista, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. Husen, Swiss Seismological Service, Switzerland*

Two relatively strong earthquakes (magnitude ML = 4.9 and 4.2) occurred in December 1999 beneath the northernmost Valtellina in the Swiss-Italian border region between the town of Bormio and Val Mustair. Both events were felt over a wide area, but no damage was reported. The immediate aftershock sequence lasted for about 1 year and consisted of 102 events that were recorded by the Swiss Seismological Service. Except for the ML = 4.3 event on April 6th 2000, all aftershocks were small (ML < 3.0). Another earthquake sequence started in October 2001 after a ML = 4.1 earthquake. The second sequence lasted for about 9 months and consisted of 66 events, including an event with ML = 3.4. After the second sequence the microseismic activity in the area continued with sporadic events until June 2004.The epicentral area is at the edge of the Swiss, Italian and Austrian seismic networks, in a geologically complex region with poorly known crustal velocities. Locations based on single national seismic network data have ill-constrained hypocenters. We thus merged the national datasets to constrain the main shock and aftershock locations. We located individual events using a probabilistic non-linear grid search algorithm. Well-constrained events indicate that the seismogenic zone is confined to the upper 10 km of the crust in agreement with results from regional moment tensor inversions. The moment tensors that are available for the five largest events of the two sequences correspond to normal faulting mechanism, with NNW-SSE oriented nodal planes. The cause for the earthquake activity is still not well understood. No geological structures that outcrop in the area can be easily related to the earthquake source.

## SPATIAL AND TEMPORAL ANALYSIS OF THE SEISMIC SERIES OF MURCIA EARTHQUAKES (2002-2005) BY USING PRINCIPAL COMPONENTS METHOD – ID 1748

*A. Posadas, Department of Applied Physics. Almeria University, Spain*
*M. Navarro, Department of Applied Physics. Almeria University, Spain*

*F. Vidal, Andalusian Institute of Geophysics, Spain*
*E. Ocaña, Andalusian Institute of Geophysics, Spain*

The Principal Components Analysis (PCA) is a powefull multivariant statistical technique that is used to find the Rupture Local Ellipsoid (RLE). This ellipsoid is a planar structure with which two variations of the method are developed: the spatial principal components analysis and the spatio-temporal principal components analysis; by using these methods it is possible to find the dominating tendencies in the fracturing processes of the seismically active volume as well as the temporal evolution of the process. This methodology has been applied successfully to several seismic series in Spain, Italy and California (USA) and now is applied to the Murcia (Spain) earthquakes occurred in two separated episodes in 2002 and 2005. Our results reveal that the main fracture during 2002 earthquakes are close to N10E trend and 2005 earthquakes are close to N30E.

## RELOCATION OF THE EARTHQUAKE ACTIVITY IN WEST-BOHEMIA / VOGTLAND REGION – ID 1786

*T. Fischer, Geophysical Institute ASCR, Czech Republic*
*A. Bouskova, Geophysical Institute ASCR, Czech Republic*
*J. Horalek, Geophysical Institute ASCR, Czech Republic*

We relocated the seismicity in the swarm-earthquake area of West-Bohemia / Vogtland in the period 1991 – 2004 with the use of total 61 seismic stations on both the Czech and German territory. The relocation was done with the aim of achieving a good control of their depth distribution. To this purpose only those events were relocated, for which at least one of the stations had to be at epicentral distance shorter than 20 km. First, the VelEst code that implements a joint inversion for determining both hypocenter coordinates and a 1-D velocity model was applied. It proved corectness of previous results, which indicated deepening of the earthquakes to the north and west. The location error was less than $\pm 0.65$ km in the central part and $\pm 2.0$ km in outer parts of the area. Second, clustering of the earthquakes was analyzed by application of the HypoDD method, which has proved the NNW-SSE elongation of the microearthquake clusters. We have also verified how the tendency of HypoDD to highlight event clustering is well-founded in the data by several synthetic examples. To quantify the lateral distribution of seismic activity we calculated a cumulative seismic moment release in rectangular cells. We found that 86% of the total seismic moment (1.4 E16 Nm) has released in the most active Nový Kostel area.

## FAULT INTERACTIONS IN NORTH AFRICA THROUGH 1980-2006 – ID 1789

*M. S. Boughacha, USTHB, Algeria*
*M. Ouyed, USTHB, Algeria*
*H. Benhallou, USTHB, Algeria*

Stress transfer between earthquakes has been a major topic during the two last decades. The concept underlies the idea that the occurrence of an earthquake caused by a fault (source) can modify the state of stress on the neighbouring faults (target): how such an event can delay, hasten and even trigger another event? Investigations are made by quantifying the induced static variations of CFF (Coulomb Failure Function), consisting of a combination of the normal and the tangential stresses. The approach stipulates that the inductive earthquake configures the space in lobes affected by positive and negative CFF variations. The first ones will be the sites of future seismicity; the latter will be devoid. The sources need to be known by their sizes (length, width, dislocation) and their orientations (focal mechanisms), as far as targets are concerned, the knowledge of their focal mechanisms is required. This issue may lead us to reconsider our perception of seismic hazard. The region under study is situated between 8°W and 10°E, and 34° N and 38° N. From 1980 to 2006, in order to study the stress transfer, this region has been divided into seven sub-regions according to their respective seismotectonic features. Through this period, this region experienced one major seismic event (1980, MW = 7.2), one strong (2003, MW = 6.8), and about ten moderate-to-strong. Starting from 1980, the cumulated variations of CFF has been computed before each given seismic event and correlations are made between the subsequent seismicity and the Coulomb Failure Function changes. Computations are the result of our own code, using the Okada's DC3D subroutine. They are made into a homogeneous half space, on a horizontal plane at a depth of 7 km.

Key words: CFF (Coulomb Failure Function), fault interaction, focal mechanism, North Africa, source fault, static stress, target fault.

## A NEW SEISMOTECTONIC MAP FOR SWITZERLAND – ID 1791

*N. Deichmann, Swiss Seismological Service, ETH-Z, Switzerland*
*S. Wöhlbier, Swiss Seismological Service, ETH-Z, Switzerland*
*D. Ballarin, Swiss Seismological Service, ETH-Z, Switzerland*
*N. Cathomen, Swiss Seismological Service, ETH-Z, Switzerland*
*J. Braunmiller, Swiss Seismological Service, ETH-Z, Switzerland*
*D. Giardini, Swiss Seismological Service, ETH-Z, Switzerland*
*A. Pfiffner, Geology, Uni-Bern, Switzerland*

Since the publication of the first seismotectonic map of Switzerland in 1978, a wealth of new data has become available. So the Swiss Seismological Service has undertaken the task of compiling a new nationwide map that displays and synthesizes the currently available seismotectonic information. As background for the tectonic information we have chosen a slightly simplified version of the new digital tectonic map of Switzerland. The new seismotectonic map is based on more than 170 high-quality earthquake focal mechanisms, that are for the most part derived from faultplane solutions based on first-motion polarities of the P-waves. However, for some of the stronger and more recent events, moment tensors derived from full-waveform inversions have also been used. Particular care was given to the selection of these data, making sure that the source of each focal mechanism is documented, so that its quality and reliability can be assessed by the user. Based on a recently completed study devoted to a comprehensive analysis of the stress field in the Swiss Alps and northern Alpine foreland, the seismological data was divided into eight different regional subsets, which differ from each other based on the predominant style of faulting or on the orientation of the principal axes of deformation. In order to visualize these differences more clearly, for each region we have plotted a rose diagram with the strike of the nodal planes of the corresponding focal mechanisms and a stereo-plot with the orientation of the P- and T-axes. One of the main goals in compiling this new map was to create a database and a mapping tool that can easily be updated as new information becomes available and that is flexible enough to be able to generate new maps meeting the needs of the user both in terms of data selection and regional focus.

## GEOPHYSICAL COMPLEX INTERPRETATION OF THE ISOSEIST MAPS OF THE MAJOR VRANCEA EARTHQUAKES – ID 1853

*A. Pantea, National Institute for Earth Physics, Romania*
*A. Constantin, National Institute for Earth Physics, Romania*

Geophysical complex interpretation of the isoseist maps is a complex undertaking, for it draws on a vast amount of knowledge in numerous sectors of Geosciences, particularly Solid Earth Physics as a branch of Geophysics that also includes Seismology, Tectonophysics, Gravimetry, Geomagnetism, Geochronology. It involves processing the results of complex geophysical, seismologic, tectonic, and geologic studies. To get a picture of, and understand, the laws that govern seismogenesis, one has to know what the relations are among the measured physical quantities indicating the properties of the rocks (whether gravimetric, magnetometric, electrometric, seismometric, or others), the dynamics of tectonic structures, as well as the nature and geological characteristics. Deep fractures affecting the crystalline base and its compartments have been revealed in the Alpine-Carpathian folding areas. In a few cases, these fractures have pierced through the deep structure of the mountain system, the depressions and the base of the Carpathian avanfosse, leading to a consistent image of the space

distribution and compartments of the Romanian crystalline base and making it possible to correlate this deep structure information with geological surface data, to a large extent, with the isoseist maps of the major Vrancea earthquakes of March 4, 1977, August 30, 1986, May 30, 1990, and May 31, 1990, and naturally with the Seismic Zoning Map of the Romanian Territory. Moreover, a correlation can be found between the isoseist maps of these earthquakes and the images of the regional Bouguer anomalies, those of isostatic anomalies, and those of the regional free-air anomalies. The results of these correlations advocate the need for integrated geological-geophysical-seismologic studies of the territory as a background for the assessment of seismic hazards.

### THE ML-4.9 VALLORCINE (FRENCH ALPS) EARTHQUAKE (8 SEPTEMBER 2005): A RIGHT-LATERAL STRIKE-SLIP ON THE N60E-STRIKING LORIAZ FAULT – ID 1862

*F. Thouvenot, LGIT, Observatoire de Grenoble, France*
*J. Frechet, IPGS, Ecole et observatoire des sc. de la Terre, France*
*M. Frogneux, IPGS, Ecole et observatoire des sc. de la Terre, France*
*N. Deichmann, SED, Federal Institute of Technology, Switzerland*
*M. Cara, IPGS, Ecole et observatoire des sc. de la Terre, France*

On 8 September 2005 at 11:27 UTC, the ML-4.9 Vallorcine earthquake struck the north-western Alps. With an epicentre located 10 km north of Chamonix (France), it was felt over a broad area with a radius of up to 200 km covering the border region between France, Switzerland, and Italy. To obtain a detailed description of the fault segment that ruptured in 2005 and to investigate its relation with the Remuaz normal fault which is thought of to be the source of the 1905 M-5.5 Chamonix earthquake, a temporary seismic network of 27 mobile stations was installed in the epicentral region.

A total of 401 aftershocks were recorded and located over a 4-month period, with magnitudes between -0.8 and 2.4. They divide into three clusters. The main cluster (about 50 % of the activity) was active from the very beginning and throughout the whole recording period; it defines a 3-km-long subvertical fault segment, oriented N60°E, at a depth between 3 and 5 km below sea level. It is located under the Loriaz Massif, some 4 km NNW of the Remuaz Fault. Assuming that this fault segment corresponds to the mainshock rupture, it reveals a hitherto unknown hidden fault (Loriaz Fault). The focal mechanism of the main shock shows a right-lateral strike-slip (azimuth N55°E), in good agreement with the main cluster geometry and with the seismotectonics of the western Alps. It does not support a slip on the N20°E-striking Remuaz normal fault.

The two other clusters were located 2 and 5 km to the northwest, i.e. in a direction perpendicular to that of the Loriaz Fault. They initiated several days after the mainshock and suggest that even a moderate-magnitude earthquake has the capacity to trigger aftershocks at distances larger than the source zone itself.

### A COMPARISON OF TECTONIC DEFORMATION STYLES WITH GUTENBERG-RICHTER B-VALUES IN THE ITALIAN AND MEDITERRANEAN AREAS – ID 1864

*B. Lolli, University of Bologna, Italy*
*G. Vannucci, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*P. Gasperini, University of Bologna, Italy*

Some recent analyses, using available CMT catalogs, evidenced the existence of a relation between the Gutenberg-Richter b-value and the tectonic style of seismic release, both at a global (Harvard CMT) and a regional scale (California and Japan). In particular extensional mechanisms would correspond to higher b-values than compressive ones. In this work we attempted to verify such findings for the Italian and Mediterranean areas using a slightly different procedure. We performed our analysis subdividing the areas according to different criteria (regular grids of various shape and size, available seismotectonic zonations, etc.) and assuming different seismogenic thicknesses. In each subdivision, we compare the tectonic style inferred from the moment tensor sum of all available mechanisms with the b-value computed from hypocentral catalogs. To characterize the style of seismic release we take advantage of some regional MT catalogs (INGV and ETH) and of an upgraded implementation of EMMA database, including more than 8000 focal solutions taken from the literature, in addition to Harvard CMT. To compute the b-value for the Mediterranean region we use the ISC catalog with the moment magnitude consistently recomputed from available magnitude estimates. For Italy we use instead a combination of CSTI and CSI catalog which both report compatible estimates of local magnitude.

### SEISMIC ACTIVITY BETWEEN CENTRAL AND SOUTHERN APENNINES (ITALY) – ID 1868

*G. Milano, Osservatorio Vesuviano - INGV, Italy*
*R. Di Giovambattista, INGV - Roma, Italy*
*G. Ventura, INGV- Roma, Italy*

The area between latitude 41°20' – 42°10' is considered a transition zone between Central and Southern Apennines. The seismic activity in this area is quite similar to that of the Apennine Chain: predominant normal faulting earthquakes linked to faults striking along the NNW-SSE chain axis. Last relevant seismic crisis in the area started on 7 May 1984 with an event of moderate magnitude (Ms=5.5), followed by intense seismic activity and a second shock on 11 May (Ms=5.2. Large historical destructive earthquakes with intensity values up to X MSC occurred to NW (1915, Fucino earthquake) and to SE (1805 Boiano earthquake) of the 1984 epicentral area. The focal mechanism of the two main shocks and the spatial distribution of the 1984 sequence suggest that this sequence was controlled by NNW-SSE normal faults and by NE-SW second order faults systems. Since 1984, the background seismicity of the area was characterized by isolated events with MD $< 3.0$ to which are superimposed low magnitude seismic sequences (1986 and 2001) and temporal and spatial limited swarms type activity like those occurred in 1999 and 2000. The spatial distribution of these two swarms activity show a NE-SW alignment located to SSE (1999) and to NNW (2000) of the 1984 epicentral area. The focal mechanisms of the events of the 2000 seismicity show a prevalence of strike slip solution with ENE-WSW and NNW-SSE striking planes. The spatial distribution and the fault plane solutions of the 1999 and 2000 seismic swarms suggest that these seismic crisis developed along NE-SW active faults that border the 1984 epicentral area.

### NEW SATELLITE BB NETWORK OF WESTERN GREECE AND ITS APPLICATION TO THE M5 EARTHQUAKE SEQUENCE OF ZAKYNTHOS, APRIL 2006 – ID 1869

*G. A. Tselentis, University of Patras, Seismological Laboratory, Greece*
*E. Sokos, University of Patras, Seismological Laboratory, Greece*
*A. Serpetsidaki, University of Patras, Seismological Laboratory, Greece*
*J. Zahradnik, Charles University, Faculty of Math. and Phys., Czech Republic*
*J. Jansky, Charles University, Faculty of Math. and Phys., Czech Republic*
*V. Plicka, Charles University, Faculty of Math. and Phys., Czech Republic*

The University of Patras, Seismological Laboratory (UPSL) and the Charles University in Prague operate standalone broad-band seismic stations (Guralp CMG-3T) in western Greece since 1997. Recently at two stations satellite telemetry has been added and they have been connected to the new BB network installed by UPSL (Patras SateLlite NETwork-PSLNET). PSLNET uses Nanometrics Trillium40s seismometers and real-time satellite telemetry with a final aim to cover western Greece with a broad-band network of 17 stations. Current status is presented and its usefulness is demonstrated on the analysis of the M5 sequence near Zakynthos in April 2006. Advantages of the near recording distances for the studied events (less than 200 km), compared to the waveforms

available through international seismological service on Internet, are discussed. Moment tensors of the three M5 events are computed with the recently developed software ISOLA (a combined Fortran-Matlab tool). Although the three events occurred close to each other, and have similar reverse mechanism, one of them features a very high non-shear component. Methodical issues of the source parameter retrieval of complex sources are discussed.

### WAVEFORM INVERSION OF M4 EVENTS IN THE GULF OF CORINTH – ID 1880

*J. Jansky, Charles University Prague, Fac. of Math. and Phys., Czech Republic*
*J. Zahradnik, Charles University Prague, Fac. of Math. and Phys., Czech Republic*
*O. Novotny, Charles University Prague, Fac. of Math. and Phys., Czech Republic*
*V. Plicka, Charles University Prague, Fac. of Math. and Phys., Czech Republic*
*G. Stavrakakis, National Observatory of Athens,Inst.of Geodynamics, Greece*

Complex tectonics of the western part of the Corinth Gulf, Greece, calls for precise source studies. This contribution focuses on 7 earthquakes M3 to 4.5. Moment tensors of such events are not available from agencies. At the same time, focal mechanisms cannot be always resolved from the first-motion polarities at local short-period stations (e.g. the Corinth Rift Laboratory network) because of insufficient coverage of focal sphere. Therefore, we do waveform inversion. To minimize problems with unknown crustal structure details, we select the lowest available frequencies, viz 0.08-0.15 Hz. Due to relatively low magnitudes, this is a non-trivial task. Indeed, stations at distances $> 70$ km have too small S/N ratio, while local strong motion stations have their low-frequency signal below the instrumental noise level. Thus we work with not more than 6 nearest broad-band stations, at distances $< 150$ km: SER and MAM (CMG-3T, Charles and Patras University), and RLS, VLS, EVR, ITM (Le3D/20s, NOA). Long-period disturbances due to local tilt at SER station are detected and removed. Several 1D crustal models have been found from fully non-linear and linearized inversions of local travel time data (CRL data). Focal mechanisms are predominantly of normal type, but far from being the same. Probably the most interesting result is the centroid depth. Two events have an extreme depth, viz 100 km for event 20050529 (connected with the Hellenic subduction zone), and a very shallow depth for M3 event 20021203 (at about 1-2 km, not typical for the region at all). The 20031118 earthquake of M4.5, occurring at $< 10$ km from SER, enabled also a unambiguous identification of the near-field effect. Results will contribute to further improvement of top-crust model by waveform inversion, and perhaps also to interpretation of strain observations on Trizonia island (3HAZ project, coordinated by P. Bernard).

### RECENT SEISMICITY OF NORTHERN CAUCASUS. NEW INVESTIGATION POSSIBILITIES – ID 1896

*A. Malovichko, Geophysical Survey RAS, Russian Federation*
*O. Starovoit, Geophysical Survey RAS, Russian Federation*
*I. Gabsatarova, Geophysical Survey RAS, Russian Federation*
*D. Mekhrushev, Geophysical Survey RAS, Russian Federation*
*E. Pogoda, Geophysical Survey RAS, Northern Osetiya Departmen, Russian Federation*

Northern Caucasus is one of the most seismically active regions of European part of Russia. Its most part is situated at the Alpine-Himalayan collision belt between the tec-tonically active Arabian and Eurasian plates. Several catastrophic earthquakes took place in this region and near its borders. The last was Racha earthquake of April 29, 1991 with Ms=6.9. Most of major Northern Caucasus earthquakes had the foci at rather small depths and they produced the considerable damages at the earth's surface. To the end of the 80th of 20th century the monitoring network of Caucasus had in-cluded more then 100 seismic stations in the framework of seismic system of the former USSR. It allows studying regional seismicity from relatively low magnitude levels (1.5 – 2,0). The collapse of the USSR led to the collapse of the seismic observation system in the Caucasus region, including its Northern part. Approximately half of seismic stations were closed. Only in last few years the system of seismic observation in the central part of Rus-sian Northern Caucasus was substantially developed. To the beginning 2005 the modern local seismic network was installed in the central part of Northern Caucasus – in North-ern Osetiya Republic. It includes 12 shot period digital seismic stations and allows moni-toring the seismicity of the territory of all adjacent Russian republics (Chechen, Kabardino-Balkarian, Ingush, Dagestan) and northern part of Georgia. In 2005 more then 1000 earthquakes were located at this part of Caucasus. In the period January – March 2006 more then 700 earthquakes were recorded. The most part of events (470) was connected with aftershock process of major (Ms=5.1) earthquake of February 6 (04h 08m) on the territory of Northern Georgia. The epicenter of this earthquake is coinciding with the epicenter of the Racha earthquake. The obtained data allowed investigating the detailed structure of the aftershock process of this earth-quake.

### HIGH-PRECISION LOCATIONS OF THE SEISMICITY IN SOUTHEASTERN SICILY (ITALY) – ID 1905

*I. Agostino, Dept. Scienze Geologiche, Italy*
*D. Patané, INGV - CT, Italy*
*G. Patané, Dept. Scienze Geologiche, Italy*
*S. La Delfa, I.R.M.A. - O.Me.G.A., Italy*

This study focuses on earthquake hypocenter locations and associated rupture mechanisms of ca. 120 events recorded in the southeastern Sicily between 2000 and 2005, with the main goal of: i) checking the robustness of the Hyblean Plateau's 3D velocity model (Scarfi et al., 2006) and ii) identifying the main seismogenic zones in the area. Both absolute and differential arrival times of the recorded local earthquakes (Ml between 1 and 3.9), acquired by two local networks (the INGV-CT and the PRR), have been used for high-precision event locations. The TomoDD code (Zhang and Thurber, 2003) was used by combining 1900 absolute travel times and 2100 catalog-derived differential times. 3D locations have been compared with those derived by the application of Hypoellipse program (Lahar, 1999) using 1D velocity model (Musumeci et al., 2003), which represent the best preliminary locations performed for surveillance purposes at INGV-CT. We found that the application of TomoDD code collapse part of the scattered seismicity, highlighting some spatial clusters of earthquakes Finally, the computed fault plane solutions are analyzed jointly with the geophysical and geological information available in the literature in order to improve our knowledge of the crustal structure and seismogenetic faults in the area.

### RECENT SEISMIC ACTIVITIES IN THE GULF OF ADEN – ID 1908

*J. M. Sholan, National Seismological Observatory Center, Yemen*

The high seismic activities observed in the southwestern corner of Arabian plate during the last ten years by Yemeni seismological network are located in the western portion of the Gulf of Aden. Complex geology, tectonic setting in the area; gives interesting elements of correlated historical seismic file obtained from regional and international seismological networks (1900-1994) and more recent seismic file (1994-2005). Earthquake epicenters maps are connect with previous geological and seismic investigations after December 1982 (M 6.0) damaging earthquake, as well as disturbance earthquake swarms in different locations of Yemen territory, during last ten years. Dealing these data with Sicilia D., et.al., 2003 tomography have been obtained by share wave velocities for the upper mantel in Afar Hotspot. Faulting system which reported in Yemeni geological map as well as quaternary volcanic fields were figured in this study within historical and recent catalogues. Seismicity of the Aden Gulf is shows average annual 50% of total events located by Yemeni network.

### ATTEMPT FOR ASSESSMENT OF PARAMETERS' RELIABILITY – ID 1910

*H. Harutyunyan, National Survey For Seismic Protection of RA, Armenia*

Author of this abstract and the specialists of NSSP of RA, in 1997 in the frame of GSHAP programme performed the attempt for assessment of the reliability of the historical strong earthquakes parameters. A new notion is the coefficient (K) of reliability of main parameters (time, location, strength) of each seismic event has been introduced into nowdays catalogue compiled. In dependence upon the imformation source, the K value may change from the maximum value (K=1.0) to the minimum one (K=0.1). Difference of the reliability coefficient (K) from the accepted methods of assessment of accuracy of the seismic event main parameters is that the former evaluates the imformative capacity of the method (criterion) for determination of those parameters. Proceeding from the values of the reliability coefficients is determined the degree to which each seismic events is studied. The above mentioned attempt required subsequent development and correctives of the criteria for assessment. On the basis of analysis existing modern methods (Russian [Shebalin, N.V., Tatevossian, R.E. (and others) (1997), Catalogue of Large Historical Earthquakes of the Caucasus, Kluwer Academic Publishers, 201-232, Netherlands], European [Stucchi, M. (1998), A Basic European Catalogue and a database for the evaluation of long-term seismisity and seismic hazard, EC series, Brussels]), as well as the method [Pirousian, S.A., Balassanian, S.Y., Avanessian, A.S., Harutunian, H.H. and others (1997), The Catalogue of Strong Earthquakes in the Territory of Armenia and Adjcent Regions, Kluwer Academic Publishers, 313-331, Netherlands] elaborated in the NSSP RA in 1997 an attempt to develop and supplement those methods based on my individual studies has been made. The hierarchical scale of the root classes received in the result of the suggested new method for each of seismic parameters allows to deepen the degree of reliability of study for each of basic parameters of each earthquake.

### AN EARTHQUAKE CATALOGUE FOR GERMANY AND ADJACENT AREAS CONSIDERING ENGINEERING DEMANDS – ID 1956

*L. Ahorner, Germany*
*S. Amstein, Earthquake Damage Analysis Center, Germany*
*C. Golbs, Earthquake Damage Analysis Center, Germany*
*H. Meidow, SeismoGeologisches Buero Dr. Meidow, Germany*
*J. Schwarz, Earthquake Damage Analysis Center, Germany*

Currently, various earthquake catalogues are available for the seismic areas of Germany and adjacent countries. Due to obvious discrepancies concerning relevant parameters, the extent of published data and the covered time window, it was decided to create a new, revised earthquake catalogue. Different techniques for data comparison and data management were developed and applied for elaborating the final version.

The basic data are provided by a magnitude ML - based catalogue, unpublished to date, by L. Ahorner, which was developed and maintained over several decades of seismo-engineering and instrumental practice. Recently published reinterpretations of historical earthquakes are included. Fake events and inconsistencies between the catalogues are identified by comparing the original datasets. For a large number of relevant events with intensities I >= 5.0, referenced sources were investigated, leading to the interesting conclusion that over the generation of catalogues the responsible authors have contributed to significant confusion of reported facts and assigned parameters. This is particularly true for macroseismic intensity, epicentral coordinates and source depths. To make the final catalogue entries more transparent, the basic, decision-supporting information will be summarized and published within a series of papers.

Working in this field it becomes clear that more information on earthquakes is available than a catalogue of the common type could preserve. Therefore the catalogue is arranged as a database system and linked to a Geographic Information System (GIS). In ongoing works the prerequisites are provided to include damage cases (pictures, floor plans e.g.), macroseismic as well as shake maps and strong motion recordings. In the final stage of the intended work, catalogue entries are prepared as one module of an extended tool for risk assessment tasks, including the evaluation of regional predominant building types. The earthquake catalogue will be maintained by the Earthquake Damage Analysis Centre (EDAC) at Bauhaus-Universität Weimar.

### SEISMOTECTONICS OF SKAGERRAK – ID 1964

*M. Sørensen, University of Bergen, Norway*
*J. E. Lie, RWE Dea, Norway*
*J. Havskov, University of Bergen, Norway*
*K. Atakan, University of Bergen, Norway*

The seismotectonics of the western Skagerrak Sea between Norway and Denmark have not been well resolved due to large uncertainties in earthquake locations. The newly installed SNART station in southern Norway and the combination of Norwegian and Danish data provide more reliable earthquake locations, which are combined with new findings from seismic data to reveal clues about the origin of earthquake activity. The relocated earthquakes fall in two main groups, one associated with the Sorgenfri-Tronquist Zone (STZ) and the other striking N-S in a band between 6.5-7°E, between the STZ and 57°N. Reinterpretation of old seismic data crossing the N-S alignment of earthquakes shows that the event locations coincide with a new structure, named the Langust fault zone, which appears to be of more recent age than the neighboring Hummer, Krabbe, Kreps and Holmsland Fault Zones. The Langust fault zone is believed to be the origin of the N-S aligned earthquake activity. Furthermore, gravity and magnetic anomaly data indicate that this zone may be related to deep-seated crustal structures. The regional stress orientation with maximum horizontal compression in the NW-SE direction agrees well with observed normal, oblique normal and left-lateral strike-slip fault mechanisms of earthquakes in the region.

### ATLAS OF ISOSEISMAL MAPS OF SELECTED GREEK EARTHQUAKES (1956-2003) – ID 1996

*Z. Schenková, Inst.of Rock Structure & Mechanics, Acad.Sci., Czech Republic*
*I. Kalogeras, Geodynamic Institute NOA, Greece*
*V. Schenk, Inst.of Rock Structure & Mechanics, Acad.Sci., Czech Republic*
*R. Pichl, Inst.of Rock Structure & Mechanics, Acad.Sci., Czech Republic*
*M. Kourouzidis, Geodynamic Institute NOA, Greece*
*G. Stavrakakis, Geodynamic Institute NOA, Greece*

The Geodynamic Institute NOA collected and evaluated macroseismic observations within the area 33N–42N and 19E–29E. The procedure of macroseismic data collection and manipulation with additional information for their interpretation were semiautomatized. The questionnaire was improved including more detailed description of damage without affecting grading according to the MM intensity scale. Easy access to the developed macroseismic database allows 43 earthquakes from period 1956-2003 to be selected and their isoseismal maps to be drawn by kriging method. After exhaustive analyses and tests intensity data the Institute of Rock Structure and Mechanics AS CR within the bilateral Czech-Greek science collaboration defined kriging default option with the aim to assign as much as possible unbiased map drawing, i.e. incorporating minimum variable parameters. The set of 43 isoseismal maps create the substantial part of the atlas of isoseismal map of Greece issued recently. Beside maps the atlas contains a table summarizing seismic parameters of all 43 earthquakes (date, origin time, coordinates, depth, Ms, Imax, number of sites where earthquake was felt, region etc.), map of epicentres, brief description of these earthquakes and their site effects, related bibliography.

### RECENT SEISMIC ACTIVITY IN THE CAMPANIAN PLAIN (SOUTHERN ITALY) – ID 2001

*G. Milano, Osservatorio Vesuviano - INGV, Italy*

The Campanian Plain, witch includes Ischia, Procida, Somma-Vesuvio and Campi Flegrei active volcanic complexes, is a NW-SE elongated structural depression bounded to the north-east by the Southern Apennines Chain and to the south-west by the Tyrrhenian Sea. With the exception of the local seismicity of the Vesuvio and Campi Flegrei, the background seismicity of the area is scarce and it is characterized by temporally and spatially isolated events with MD $< 3.5$. The location of these events fall on the first outcrop of the Apennines Chain. The most relevant seismic event detected in the area occurred on 14 February 1981 (Ms = 4.6). The focal mechanism of this event shows strike-slip solution with NNW-SSE and ENE-WSW striking planes; T-axis agrees with the large scale extensional stress regime acting in the Southern Apennine Chain. Closeness the epicentral area of this earthquake a seismic activity occurred in 2005. This seismic activity lasted few days and was characterized by a swarm type activity. Almost all events of this swarm had magnitude less than 2.5 and only two events had MD=3.6. The spatial distribution of this seismic activity aligned along WNW-ESE direction and the fault plane solutions of the two most energetic earthquakes show a nodal plane striking approximately WNW-ESE. The spatial distribution of the events and the fault plane solutions suggest that this seismic crisis developed along active fault(s) nearly parallel to the NW-SE Apennine faults.

## SC-A 2: Volcano Seismology and Applications to Hazard Evaluation

Level 2

### TEIDE - PICO VIEJO, TENERIFE, SPAIN: WHAT CAN SEISMIC NOISE MEMORY TELL US? – ID 1751

*R. Carniel, Università degli Studi di Udine, Italy*
*M. Tárraga, Museo Nacional de Ciencias Naturales, CSIC, Spain*
*O. Jaquet, Colenco Power Engineering Ltd., Switzerland*
*A. García, Museo Nacional de Ciencias Naturales, CSIC, Spain*

The possible reawakening of Teide - Pico Viejo volcanic complex is currently a matter of scientific debate. One of the continuous signals that can be most easily sampled and monitored is the seismic noise. In this work we investigate the time evolution of this seismic noise in terms of its memory. A random series is supposed to show no persistence, while a signal generated by a coherent process is supposed to show a behaviour correlated in time, i.e. to show a certain degree of persistence, or, as we call it here, "memory". This can actually be quantified with geostatistical tools such as the variogram, already successfully applied at many active volcanoes at different time scales, from minutes to thousands of years. The persistence we are studying here is also an important prerequisite that time series observed at active volcanoes must exhibit in presence of precursory behaviours in order to provide valuable information for forecasting. In particular, at Teide – Pico Viejo the recorded seismic noise is the superposition of at least two (classes of) signals: an anthropogenic one, and a natural one. These are shown by the variogram to be characterized by different levels of persistence in different frequency bands.

### GEOPHYSICS AROUND AN ICELANDIC HYDROTHERMAL HEAT SOURCE: DEVELOPING A MEANS FOR MAGMA MONITORING – ID 1850

*D. Kahn, Duke University, United States*
*S. Onacha, Duke University, United States*

Krafla is an Icelandic caldera, with an extended network of fissures. The caldera is home to both an important geothermal power station and a highly active volcanic system. A 1975-84 fissure eruption, consisting of a series of 21 tectonic events and 9 eruptions, resulted in lava covering nearly 40 km2. The eruptions jeopardized the completion of the Krafla geothermal power station because of safety concerns and the volcanic contamination of the production wells. Thus, at Krafla, power generation and volcanic hazards are directly linked to each other. Efficient geothermal power development and hazard monitoring depend upon the accurate location of Krafla's active heat sources. Developing joint geophysical imaging methods that couple seismic, magnetotelluric (MT), and time domain electromagnetics (TEM) is a step toward mapping out these structures. In 2004 and 2005, we deployed 33, 3-component, Geospace GS-1, 1Hz sesimomographs, and 109 Phoenix MT stations at sites in the Krafla geothermal field. The boundary between the high and low resistivity regions in the Krafla geothermal field has been mapped using the MT method with TEM static shift correction. The boundary is associated with a rapid change in temperature and is interpreted as the edge of a heat source, most likely a magma body. Hypocenter locations for local microearthquakes have also been determined, and preliminary analysis indicates that most of the earthquakes occur at the boundary. We find good correlation between resistivity, location of microearthquakes, postulated volcanic activities, fluid flow, and structural anisotropy. Furthermore, the analysis of polarization directions for MT data at high frequency, corresponding to shallow depths, shows very similar orientation to the polarization determined by shear wave splitting. The new coincident MT and microearthquake imaging procedure has provided complementary information and should be of value in monitoring the geothermal field.

### TIME VARIATION OF SPECTRAL AND WAVEFIELD FEATURES OF VOLCANIC TREMOR AT MT. ETNA DURING 1999. – ID 1925

*S. Alparone, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Cannata, Dipartimento di Scienze Geologiche, Università di, Italy*
*A. Catania, Dipartimento di Scienze Geologiche, Università di, Italy*
*S. Gresta, Dipartimento di Scienze Geologiche, Università di, Italy*

We have studied the volcanic tremor recorded at Mt. Etna during 1999, by using three-component seismic stations. This time period was characterised by both explosive and effusive eruptions occurred at the summit craters. During the first half of the year volcanic activity consisted in a quiet lava effusion from a fissure at the base of the SE Crater. We found significant time variations in the trend of the overall spectral amplitude of tremor, as well as in the dominant spectral peaks. Moreover, the tremor wavefield features (polarization, particle motion and ratios between the amplitude of the three components of the ground displacement) have been studied too, confirming significant time variations. This lead us to suggest the existence of at least two tremor sources: a shallow one, mainly characterised by relatively high frequencies (3.5-7 Hz), is linked to the upper portions of the active conduits, and directly related to the observed eruptive activity. The latter deeper source was active only few weeks, and characterised by frequencies lower than about 2.5 Hz. It has been roughly located south-west of summit area, 3 km b.s.l. The second half of the year has been mainly characterized by short lived lava fountains at three of the four summit craters: Voragine, Bocca Nuova and SE Crater. The analysis of volcanic tremor was mainly devoted to six lava fountain episodes. A general behaviour at the different craters was observed: i) a gentle increase of the tremor amplitude during the strombolian activity preceding the lava fountain; ii) the highest values during the paroxysmal (lava fountain) phase; iii) a sharp decrease following the end of the fountains. In spite of this common behaviour, some differences were evidenced in the energy content at different frequency bands, and in the spectral ratios by considering the lava fountains at the different craters.

### ROCKFALL EPISODES ALONG STRUCTURAL DISCONTINUITIES OF THE VESUVIUS VOLCANO CRATER RIM: MORPHOSTRUCTURAL STUDY AND ANALYSIS OF SEISMIC SIGNALS – ID 2000

*G. Alessio, Osservatorio Vesuviano-INGV, Italy*
*R. Nappi, Osservatorio Vesuviano-INGV, Italy*
*G. Vilardo, Osservatorio Vesuviano-INGV, Italy*
*G. Mele, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

Seismic signals recorded in volcanic areas and associated with volcanic activity can be originated from many different sources. Among various types of transient signals, i.e., explosion quakes, tectonic quakes, long period events, those related to rockfall episodes are very important because rockfalls might contribute significantly to volcanic hazard even in areas characterized by volcanic quiescence. In this study we have analyzed the intracrateric rockfall events occurred since 2001 along the Vesuvius asymmetrical crater rim. Field investigations of the main morphostructural features carried out in the summit area, along with digital images collected during the study period, allowed us to infer the time evolution and the areal distribution of the rockfalls. Two main source areas located on opposite sides of the volcanic crater, to the NW and SSE, have been identified. Both of them are characterized by intense fracturing and fumarolic emissions. Seismic signals of the intracrateric rockfall events, recorded by the broadband and short-period permanent stations operated by the Osservatorio Vesuviano-INGV of Naples and located within a few kilometers from the crater, have been analyzed in terms of duration and frequency content in order to characterize the peculiar features of the source areas.

## SC-B 0: Data Acquisition, Theory and Interpretation (Open Session – Posters Only)

Level 2

### APPLICATION OF EMD IN SEISMIC DATA TREATMENT – ID 312

*Q. Luo, Tongji University, China*
*C. Shi, Tongji University, China*

In seismic record treatment, the velocity or displacement time history curve, which is generally calculated from integrating an original acceleration. The integral curve usually deviates from the time axe. Especially for the displacement, its deviation is serious. This phenomenon is named zero-float. Huang Transform, i.e. EMD method (Empirical Mode Decomposition) can be used to pick up the mean value or trend of signals. This paper suggests to apply EMD to solve the zero-float problem. To verify its feasibility, the integrated and original seismic displacement time histories are compared with the corrected curve, which got by using EMD method. Their response spectra are also compared. We also use the acceleration data of El Centro record and its corrected displacement data by using EMD as input ground motions to calculate one structure displacement response. The analysis show that Huang transform is a useful tool to solve the deviate integral in seismic record treatment.

### THE INTERNATIONAL SEISMOLOGICAL CENTRE : AN UPDATE – ID 501

*M. Aspinwall, International Seismological Centre, UK*
*M. Bolton, International Seismological Centre, UK*
*P. Dawson, International Seismological Centre, UK*
*J. Harris, International Seismological Centre, UK*
*A. Shapira, International Seismological Centre, UK*
*D. Storchak, International Seismological Centre, UK*

The International Seismological Centre is a non-governmental, non-profit making organization, charged with the final collection, analysis and publication of earthquake source information from all over the world. Earthquake data are received from more than 100 seismological agencies representing every part of the globe. This data comprises readings from almost 3,000 seismograph stations. The ISC builds on the efforts of seismologists who run stations and networks around the world to locate tens of thousands of earthquakes each year. With the current tendency of almost all local agencies to focus their efforts on rapid dissemination of earthquake information, it is the ISC that becomes the source for the most complete earthquake information. We wait more than a year for all possible earthquake data to be collected before we start to analyze it and to edit the Bulletin. As soon as the data are parsed and inserted into the database, contributed hypocentres are grouped and phase readings are associated with the automatically selected primary hypocentres. This automatic process is repeated every few days. Many of these events will be relocated by ISC seismologists who manually review every event that complies with one of the following conditions: . The reported magnitude is higher than 3.5. . The event was reported by at least 2 agencies . The event was recorded at a distance greater than 1000 km. On the average, about 3500 events with more than 150,000 associated readings are reviewed each month. The ISC also maintains the International Registry of seismic stations (jointly with USGS/NEIC), provides links to web-sites with additional seismological information, information about seismologists and seismological institutions (national points of contact), bibliography lists, reports and documentation of ISC's software. Visit www.isc.ac.uk <http://www.isc.ac.uk/> for move details.

### DETERMINATION OF EPICENTRAL AREA ATTRIBUTES BASED ON SEISMOGRAM PROCESSING – ID 565

*K. Manova, Institute of Earthquake Engineering and Engineerin, Macedonia*
*L. Pekevski, Seismological Observatory at the Faculty of Natura, Macedonia*

For determination of epicentral area attributes we present an experience of applying image processing and pattern recognition techniques on images obtained by time-frequency transforms of earthquake seismograms. The approach is to extract, from a signal belonging to a class (epicentral area), certain attributes, which are discriminating. We call this set of attributes a signature for the associated signal. This signature can then be used to detect the presence of similar attributes in unknown data. Since the signals/seismograms of interest in this research are non-stationary, we determine the signatures based on time-frequency analyses of the signal. Our goal was to experience whether the applied transforms could provide signatures for our recognition task.

To recognize patterns, the selection of input data sets is important. The appropriate inputs should be effective to represent the characteristic of pattern. The experimental data used in this presentation were collections of seismograms of local earthquakes (M<4) from epicentral zones in Macedonia, recorded at the Seismological Observatory in Skopje (SKO) and at the seismological station in Ohrid (OHR). We did our processing on the S-P-phase part of the vertical components of the seismograms.

Time-frequency transforms decompose the preselected part of the seismogram into elementary components, the atoms. These atoms, well localized in time and frequency are linear transforms of the signal. Another approach consists in distributing the energy of the signal along time and frequency, which leads to quadratic transforms of the signal. Preliminary analysis of our data sets has shown that few time-frequency signal transforms could provide discriminable parameters for the recognition task. The following looked promising: Instantaneous frequency, Continuous wavelet transform, spectrograms and the Wigner-Ville transform.

The results demonstrate the applicability of the presented procedures, based on image processing and pattern recognition techniques, for (even automatic) epicentral zone classification.

### THE WESTERN MEDITERRANEAN SEISMIC NETWORK – ID 687

*A. Pazos, Real Observatorio de la Armada, Spain*
*J. M. Davila, Real Observatorio de la Armada, Spain*
*E. Buforn, Universidad Complutense de Madrid, Spain*
*A. Udías, Universidad Complutense de Madrid, Spain*
*W. Hanka, GeoForschungsZentrum, Germany*
*M. Benzzeghoud, Evora University, Portugal*
*M. Harnafi, Mohamed V University, Morocco*
*A. Nadji, Oran University, Algeria*

*A. Rimi, Mohamed V University, Morocco*
*H. Momsour, Oran University, Algeria*

The Royal Naval Observatory in San Fernando (ROA), together with the Complutense University from Madrid (UCM), and in collaboration with the GeoForschungsZentrum of Potsdam (GFZ), have deployed a broad band seismic network around the Alboran sea, in southern Spain, northern Africa. This network started to operate in 1996 with the installation of the SFUC station, near the Observatory. Since then, several stations have been installed and nowadays it is being in expansion with the future installation of several ocean bottom seismometers (OBS). This network is called the Western Mediterranean Network (WM). In this work the present status and the future of the broad band WM network are shown.

## A COMPARATIVE EVALUATION OF NOISE MODELS USING TURKISH STRONG GROUND MOTION DATA – ID 793

*A. Z. Denizlioglu, Earthquake Research Department, Turkey*
*E. Yenier, Middle East Technical University, Turkey*
*Z. Colakoglu, Earthquake Research Department, Turkey*
*S. Akkar, Middle East Tecnical University, Turkey*

A consistent ground-motion data processing scheme is important for most earthquake engineering and engineering seismology related research. Of the various data processing procedures filtering is the most implemented technique in removing the low- and high-frequency noise from the strong motion data. As noted by various studies the crucial point in filtering is the determination of high-pass and low-pass filter corner frequencies. In essence, the chosen filter corner frequencies should not distort the actual frequency content of the ground motion. In particular, the determination of appropriate low-cut corner frequency values is very important as they have a significant effect on the spectral features of the ground motion. This issue is more challenging for ground-motion records from analogue instruments due to their limited dynamic response range.

The main objective of this study is to determine a frequency-dependent noise model for analogue records using the available fixed trace information in the Turkish strong ground- motion data base. This model is compared by the previously proposed similar noise models in the literature to note the differences that may originate from different sensor features and digitization schemes. The filter corner frequencies computed using the noise model are also compared with the corner frequencies of some theoretical source spectra. This comparison enables one to observe whether the suggested filter cut-offs significantly remove the actual frequency content of the records based on the information revealed by the theoretical source spectra. The results and conclusions of this study are going to be used in the processing and recompilation of the Turkish strong ground-motion data base.

## FUNCTIONAL CRITERIA FOR STRONG-MOTION SEISMOGRAPHS – ID 797

*H. Avery, CSI Ltd, New Zealand*
*J. Berrill, University of Canterbury, New Zealand*
*M. Dewe, University of Canterbury, New Zealand*

This paper describes the optimum configuration for non-continuous (triggered) digital strong motion seismographs. The paper begins with a brief description of a generic signal acquisition and recording process, along with the relevant requirements. This is then extended to seismic data acquisition and recording. The paper then focuses on the particular requirements for capturing natural seismic events on a triggered basis. A summary of accepted parameters are given and particular attention is paid to the relationship of signal bandwidth to both noise floor and the capture window length. The paper then concludes with a suggested optimum configuration for triggered digital strong motion seismographs over a range of instrument noise floors and trigger levels.

## MICROSEISMICITY AND FAULTING GEOMETRY IN CENTRAL GREECE – ID 1062

*V. Karakostas, Thessaloniki University, Greece*
*C. Karamanos, Thessaloniki University, Greece*
*E. Papadimitriou, Thessaloniki University, Greece*
*I. Kassaras, Athens University, Greece*
*K. Makropoulos, Athens University, Greece*

During November 2004 – June 2005 a digital seismological network was deployed in the eastern part of central Greek mainland, in an area seismically active in the 20th century, particularly in the decade of fifties. The strongest earthquake (M=7.0) occurred in 1954, while the last strong one in 1980 (M=6.5). In total 18 Reftek digital loggers (both 72A–07 and R–130) were installed assembled with guralp CMG40T broadband and Le_1Hz seismometers. The average spacing between stations was of the order of 20 km to ensure earthquake depth accuracy. Local earthquakes with P– and S– arrivals at four or more stations were located using modern techniques as HYPOINVERSE and HYPODD. The best–recorded earthquakes divided spatially in clusters and a reasonable crustal structure for each sub area was defined. Lateral variations of the crustal model taken into account, calculating time delays for each station. By this way, earthquakes inside the network or close to its boundaries were located with accuracy less than 1 km in both the epicenter and focal depth. In addition, focal mechanisms of earthquakes with proper azimuthal coverage were computed. Seismicity covers the most of the area distributed mainly in clusters along active structures. A magnitude M=4.4 earthquake, was the largest local one recorded by this network (5 December 2004, 17:58 UTC), close to the focal area of the 1980 strong earthquake. Several cross sections striking normal to the trend of the clusters of the epicenters reveal the geometry of the active structures as well as the width of the seismogenic layer. Most of the focal mechanisms exhibit normal faulting and were used along with the microseismicity foci in the cross sections for the definition of the properties of the faults that activated during the experiment.

## WAVELET PROCESSING OF MULTICHANNEL RECORDS FOR THE ANALYSIS OF SURFACE WAVES – ID 1449

*J. J. Galiana-Merino, University of Alicante, Spain*
*P. Jauregui-Eslava, University of Alicante, Spain*
*J. Rosa-Herranz, University of Alicante, Spain*
*J. Giner-Caturla, University of Alicante, Spain*
*S. Molina-Palacios, University of Alicante, Spain*

The refraction microtemor (ReMi) technique is a proven seismic method for measuring in-situ shear wave (S wave) velocity profiles. The application of this method requires only conventional seismic equipment for recording data and ambient noise as a seismic source. In our case the equipment is the same multichannel recorder used for refraction studies, which is connected to a line of 24 vertical component geophones. After the data acquisition process, the recorded multichannel data are treated through the slowness-frequency (p-f) transform in order to separate Rayleigh waves from other seismic arrivals and obtain the shear-wave dispersion curve. Nevertheless, in general the recorded data are contaminated with stationary and local noise, as they are taken from urban areas. In other way, sometimes one of the channels fails, contaminating the data with several spikes or even making useless the information associated to it. In this paper, we apply a pre-processing stage based on wavelet analysis with the aim of reducing the previously commented problems. Concretely, the wavelet packet transform is first used to increase the signal to noise ratio of the data, which provides us clearer signals and makes easier the detection of useless channels. After that, if one of the channels is contaminated by spikes, then we apply again the wavelet analysis in this channel in order to eliminate the spikes and recover the signal of interest. Finally, the data are transformed to the slowness-frequency domain and the dispersion curve is obtained. The recorded data have been taken from the Segura river basin (southeastern of Spain) and the shear-wave dispersion curves

obtained with the wavelet pre-processing and without any previous analysis have been compared.

### KYTHERA 2006 EARTHQUAKE: DATA PROCESSING OF STRONG MOTION, FROM VARIOUS DIGITAL SENSORS – ID 1493

*A. Skarlatoudis, Aristotle University, Greece*
*B. Margaris, ITSAK, Greece*

In January 8 of 2006, an intermediate depth (d=64 km) earthquake (M6.7) occurred at the western part of the Hellenic trench near to the Kythera island (southern Greece). The earthquake was recorded by several stations of the permanent strong motion network of Institute of Engineering Seismology and Earthquake Engineering (ITSAK). The main shock triggered a number of instruments with different digital sensors (ETNA, QDR, CMG-5T) installed in these stations, which produced a high quality strong motion data set. The aforementioned accelerographs exhibit some new interesting characteristics as very long duration records and different frequency content in comparison to strong motion data recorded by shallow seismic events in the same area. Thus a specific data processing is indispensable in order to correct properly these strong-motion recordings. For all types of instruments two different corrections are applied for producing corrected values of acceleration, velocity and displacement and study analytically the noise spectrum recorded by various digital sensors. The first one is the method proposed by instrument sensor manufacturer and the second one is the method introduced by Boore, (2001;2003). Both methods are applied for all types of instruments. The Fourier and response spectra for all records and for both types of processing routines, were produced and compared. An attempt is made to compare those strong motion data with data recorded by other digital sensors recorded by other earthquakes. The previous comparisons lead to a classification of the different type instruments and it gives a strong indication about the quality of the data that can be retrieved from each type of instrument sensor.

### UNDERLYING FEATURES OF THE MICROSEISM AT ITS LOWER LEVEL OF EXCITATION – ID 1594

*J. Vila, Inst. Est. Catalans / Univ. Barcelona, Spain*
*R. Macià, Univ. Politecnica Catalunya, Spain*
*R. Sleeman, KNMI-Orfeus, Netherlands*
*A. Correig, Univ. Barcelona, Spain*

A study is made on microseism activity at its lower level of excitation, in an attempt to get some insight in its underlying features. To do so, a set of 35 world-wide broadband seismic stations have been individually analyzed for a minimum interval of time of one year in successive windows of 30 minutes. The power spectrum of each window has been computed and corrected for instrument response. The series of spectra have been sequentially compared and the frequency bin with lowest amplitude has been selected. Once the full set of data has been analyzed, the resulting spectrum for each seismic station corresponds to that of minimum amplitude which we name Base Level Noise Seismic Spectrum. By comparing the minimum spectra for all seismic stations we find that for the stations located in the northern hemisphere all spectra coalesce in shape and amplitude, being characterized by a primary peak at 0.7 Hz and a secondary peak at 0.21 Hz. Minimum spectra from continental seismic stations in the southern hemisphere have the same shape as those from continental stations in the northern one but with higher amplitude. Minimum spectra from oceanic stations show strong fluctuations in amplitude but share the same spectral peaks. As we have selected the spectra of minimum amplitude, the contribution of the different sources for microseisms can be regarded as highly reduced, and we can interpret the minimum spectra as representative of the medium response that defines a global property.

### INVESTIGATION OF CALIBRATION POSSIBILITIES FOR THE TRIPOLI SEISMIC ARRAY, GREECE. – ID 1645

*E. Pirlis, University of Athens, Greece*
*M. Spyridopoulou, University of Athens, Greece*
*M. Pirli, University of Athens, Greece*
*N. Voulgaris, University of Athens, Greece*

Tripoli Seismic Array (TRISAR), Greece, performance in terms of event location is restricted by its very small aperture and limited number of sensors. Detailed investigation of errors in location results revealed that overall performance is also affected by epicentral distance and azimuth, suggesting structural and local geology effects. In order to investigate the possibility to correct for systematic errors automatically, mislocation vectors were calculated for an extended data-set of approximately 9 months. Theoretical values were calculated based on earthquake catalogues compiled by the National Observatory of Athens (NOA) and the ISC. Resulting mislocation vectors are characterized by significant vector length, consistent with the large observed backazimuth and slowness errors, the smaller values being met in the area NE of the array and for epicentral distance values less than 200 km. As expected, resulting corrections mostly concern backazimuth values and are not able to sufficiently affect the final epicenter solution, as the largest automatic algorithm errors are observed in epicentral distance determination, a result of phase misidentifications due to low slowness resolution. A further attempt was made to calculate mislocation vectors also for manually analyzed phases, mostly in order to draw some conclusions regarding error distribution for the slowness vector. Although analyst results are characterized by significantly lower errors than automatic algorithm results, differentiations in mislocation vector length are also observed for different areas, verifying the implication of crustal structure effect in backazimuth error distribution.

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### ERROR ANALYSIS FOR EARTHQUAKE LOCATION RESULTS FROM THE TRIPOLI SEISMIC ARRAY, GREECE – ID 1646

*M. Spyridopoulou, University of Athens, Greece*
*E. Pirlis, University of Athens, Greece*
*A. Chira, University of Athens, Greece*
*M. Pirli, University of Athens, Greece*
*N. Voulgaris, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*

The Tripoli Seismic Array (TRISAR) is an experimental small-aperture array of 4 elements, operating since July 2003 in central Peloponnese, Greece. To obtain earthquake location results, data undergo a real-time processing simulation and analyst review. Validity of results is assessed by comparison to location results calculated by the National Observatory of Athens (NOA). A detailed analysis in location errors both for automatic and analyst results is performed, in order to evaluate array performance and investigate possibilities of enhancement. Automatic algorithm results are significantly influenced by its inefficiency to analyze in an integrated manner very local and near-regional seismicity, as well as highly clustered seismicity, as aftershock sequences. Manually obtained location accuracy is mostly depending on array configuration and resolution. Results are presented according to epicentral distance and azimuth, as there appears to be a strong dependence of location results quality on these two parameters. Differentiation of array performance depending on azimuth suggests local geology and crustal structure effects. Furthermore, array contribution to earthquake location in Greece supplementary to existing, conventional seismographic networks is investigated by producing location results using jointly array and network data, mainly focusing on offshore areas of poor azimuthal coverage by the conventional networks.

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### ANALYSIS OF DAMPING AND NATURAL PERIOD OF SEISMOMETERS GURALP CMG 40T – ID 1666

*I. Tasic, Environmental Agency of the Republic of Slovenia, Slovenia*
*P. Sincic, Environmental Agency of the Republic of Slovenia, Slovenia*
*P. Zupancic, Environmental Agency of the Republic of Slovenia, Slovenia*

Characteristic values of seismometers are damping and natural period which are usually given by the producer. For controlling the quality of the seismometer's transfer function, it is enough to evaluate these two parameters. Periodically control of damping and natural period in the longer time period estimates stability of seismometer's transfer function. Seismic stations of the Slovenian National Seismic Network are equipped with a Quanterra Q730 data logger and mostly with broadband seismometers Güralp CMG 40T. All stations are telemetrically connected to the network center via TCP/IP in real time. We have developed our own software for seismometer calibration. Calibration signal is started and seismometer response analysis is carried out automatically. This task is done telemetrically using step calibration signal built in Quanterra 730. 22 seismometers are tested periodically from the beginning of the year 2004. According to our tests, the results for some sensors differ from the factory specification almost 5 %, but during two years period, damping and natural period have been stable, the maximum change was less than 0.7 % and the average was less than 0.4 %.

### USING ARTIFICIAL NEURAL NETWORKS FOR DETECTING FIRST P WAVE ARRIVAL – ID 1667

*I. Tasic, Environmental Agency of the Republic of Slovenia, Slovenia*
*P. Sincic, Environmental Agency of the Republic of Slovenia, Slovenia*
*P. Zupancic, Environmental Agency of the Republic of Slovenia, Slovenia*

The study of using simulated neural networks in automatic procedure for P seismic wave detection in the local earthquake records is presented. Two types of simulated neural networks have been used: a neural network with radial basic functions and a neural network with sigmoid functions. In the process of detection of P seismic wave arrival, first a record of the earthquake was converted into a characteristic data vector. After that characteristic data vectors were converted into a vector of significance. The operation was carried out with neural networks. The maximum values of the vector of significance characterized the arrival of seismic waves. The neural network with radial basic functions and a neural network with sigmoid functions were trained with the same set of seismic data and tested on another set of local earthquake waveforms. Results between both artificial neural networks did not differ significantly, but the neural network with radial basic functions better visualizes possibility of first P arrival. Using artificial neural networks gives better results than STA/LTA trigger algorithm.

### BROADBAND SEISMIC DATA ANALYSIS AND QUALITY CONTROL PROCEDURES IN (NEAR) REAL-TIME AT THE HELLENIC BROADBAND SEISMIC NETWORK OF THE NATIONAL OBSERVATORY OF ATHENS, INSTITUTE OF GEODYNAMICS – ID 1679

*N. Melis, Institute of Geodynamics, NOA, Greece*
*J. Vila, Institut Estudis Catalans, Spain*
*R. Macià, Universitat Politecnica de Catalunya, Spain*
*A. Correig, Dept. Astronomia i Meteorologia, U. Barcelona, Spain*
*G. Stavrakakis, Institute of Geodynamics, NOA, Greece*
*K. Boukouras, Institute of Geodynamics, NOA, Greece*
*K. Konstantinou, Institute of Geodynamics, NOA, Greece*
*E. Sangriotis, Dept. Informatics and Telecommunications, NKUA, Greece*
*E. Koutsoukos, Signal Proc. Lab., UMHHRI, Greece*

By means of a Bilateral Cooperation between Spain and Greece, a near real-time quality-control system has been setup at the Institute of Geodynamics of the National Observatory of Athens to monitor the status of all incoming broadband seismic stations recorded by the Hellenic Broadband Seismic Network (http://bbnet.gein.noa.gr). The system operates since 2005 and allows continuous monitoring of any considered parameter suitable to get significant information about the site and instrument behavior. The system is developed by means of software implementations in a single Linux / PC computer using the "cron" facilities of Linux operating systems. The aim is to detect potential problems and to generate automatic warnings when anomalous signals are present. The analysis is done both in time and in frequency domain, considering segments of a definite length. Averaged amplitudes and averaged squared amplitudes of ground motion waveforms are obtained for each segment. The spectral analysis is based on power spectral density and considers 12 frequency bands. Through this analysis, new time series are generated, and they are ready to apply algorithms for the detection of intrinsic malfunctioning. These time series are used to detect malfunctioning and to quantify the most interesting characteristics of the signals. The quality control outputs allow the characterization of recording sites, evaluating the minimum level of noise for all spectral components. This procedure is performed by means of a continuous comparison of the output spectra with respect to the stored results. After a long term operation this let us to obtain a pseudo-spectrum that can be considered as the minimum noise in absence of any type of transitory signal, for a given site. Once the minimum level is reached, permanent site effects are visualized and the definition of algorithms to detect signals without physical sense can be highly improved.

### PERFORMANCES OF TWO AUTOMATIC EARTHQUAKE LOCATION SYSTEMS IN THE NORTH-EASTERN ITALY – ID 1686

*S. Gentili, OGS, Italy*
*P. L. Bragato, OGS, Italy*
*D. Pesaresi, OGS, Italy*
*A. Snidarcig, OGS, Italy*

In this poster, the new Antelope earthquake location system performances are analyzed and compared with the ones of the already existing FAAS location system. Antelope is used in the framework of the EU Interreg IIIA project started in 2002 "Trans-national seismological networks in the South-Eastern Alps" and involves Italy, Austria and Slovenia: among the scopes of the projects, there is the improving of network geometry for lowering earthquake detection threshold near the borders, by collecting data from several seismic networks in the area. FAAS is the Friuli Automatic Alert System and uses data from the Short-period Seismometric Network of Northeastern Italy (NEI). It monitors the region between Lake Garda on the West and the Italian/Slovenian border on the East as well as a limited portion of Western Slovenia and Southern Austria. It has been active at Centro di Ricerche Sismologiche (CRS), a department of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), since 1996. It recognizes local earthquakes, performs P and S picking, locates earthquakes and estimates their magnitudes. In addition, FAAS establishes the level of alert for civil protection authorities and seismological institutions. Automatic locations are also reported on the CRS web page (http://www.crs.inogs.it). In this poster, the results of the two automatic location systems are compared with the set of manual relocations of the NEI network bulletin (OGS database). The analysis on the location and picking precision is performed on the common data from the end of 2005: in particular we compute the variance of the differences between the 3 location and picking data sets, inferring the precision of each data set. In addition, the magnitude of completeness is estimated independently for each data set, depending on the area analyzed.

### BAYESIAN LOCAL WAVEFORM INVERSION IN THE PANNONIAN BASIN – ID 1687

*Z. Wéber, Seismological Observatory, GGRI, Hungary*

The central part of the Pannonian basin (mostly occupied by Hungary) can be characterized by fairly low seismicity with local earthquake magnitudes of mostly less than 3. The weak events are usually recorded at only a few stations, so reliable focal mechanism solutions can only be obtained by waveform inversion. In this study a newly developed probabilistic approach is used to invert short-period waveforms of weak local earthquakes in order to retrieve the source parameters for some events that occurred in Hungary.

The inversion procedure takes into account the effects of the random noise contained in the seismograms, the uncertainty of the hypocentre determined from arrival times, and the inaccurate knowledge of the velocity structure, while estimating the error affecting the calculated focal parameters. Assuming that all uncertainties can be described by Gaussian probability density functions (PDFs), prior information, measurement errors and theoretical errors are estimated. Then, the applied probabilistic approach maps the posterior PDFs for the hypocentral coordinates, the moment tensor, and the source time function. The final estimates for the focal parameters are given by the maximum likelihood points of the PDFs, while solution uncertainties are presented by scatter density plots. The estimated uncertainties in the moment tensor components are plotted on the focal sphere in such a way, that the significance of the double-couple, the CLVD, and the volumetric parts of the source can be assessed.

The moment tensor solutions for the selected events have negligible volumetric part, implying the tectonic nature of the events. The source time functions are usually very simple with time duration of about 0.1-0.2 seconds. The retrieved source mechanisms are in agreement with the available clear readings of first-arrival P-wave polarities and with the main stress pattern published for the epicentral region.

### SLOVENIAN NATIONAL SEISMIC NETWORK: FINAL REPORT – ID 1689

*R. Vidrih, Environmental Agency of the Republic of Slovenia, Slovenia*
*I. Tasic, Environmental Agency of the Republic of Slovenia, Slovenia*
*P. Sincic, Environmental Agency of the Republic of Slovenia, Slovenia*
*M. Zivcic, Environmental Agency of the Republic of Slovenia, Slovenia*
*J. Pahor, Environmental Agency of the Republic of Slovenia, Slovenia*
*J. Kolar, Environmental Agency of the Republic of Slovenia, Slovenia*

In 2006 the modernization of the Slovenian seismic network is completed. The project "Modernization of the Slovenian National Seismic Network" started in the year 2000. The purpose of a modernized seismic network is to enable fast and accurate automatic location of earthquakes, to determine earthquake parameters and to collect data on local, regional and global earthquakes. The first phase was built up seismic network to improve seismic activity monitoring of the Krsko basin where the Krsko nuclear power plant is placed, consisted of four stations. The next phase was to establish seismic monitoring of the Upper Soca Territory where the last strongest earthquakes occurred in Slovenia (April 12th, 1998, Ml=5.6, July 12th, 2004, Ml=4.9). The third phase was to cover areas with the lower seismic risk and at the and with the network around Ljubljana the modernization is finished. Typical station consists of two shafts. In seismic shaft Güralp CMG 40T seismometer is installed and as data acquisition system Q730 data logger is used. Communication equipment and power supply are installed in service shaft. To secure on-scale seismograms in case of a strong earthquake five stations have also Episensor accelerometer. Due to thick weathered surface layer four stations use shallow borehole seismometers. Sampling rates are 200sps, 20sps and 1sps. Real time data transfer is done using Antelope software package. The data from stations is transferred by use of the leased phone lines, HSCSD mobile phone connection and two-way satellite broadband internet. The detection and location capabilities of the network are being improved even better than it was expected. A lot of procedures are automated as real time monitoring of data flow reading of the latency of the data coming to the main object ring buffer, monitoring the state of health of seismic stations, regular periodic calibration of seismometers, etc.

### THE REGIONAL DATA CENTRE SZGRF – ID 1764

*K. Stammler, SZGRF/BGR, Germany*
*K. Klinge, SZGRF/BGR, Germany*

The Seismological Central Observatory Graefenberg (SZGRF), a part of the Federal Institute of Geosciences and Resources (BGR), is the data centre for the German permanent digital broadband stations. The core of this station set is the Gräfenberg-Array (GRF) and the German Regional Seismological Network (GRSN). GRF and GRSN are the two major broadband station systems within Germany. The 13 stations of the GRF array are in full operation since 1980 and the GRSN project started in 1991. Currently a total number of 41 stations is contributing to the continuous waveform archive of the SZGRF. The size of the data archive is about about 1 TByte, all data are automatically accessible using Raid-Systems and DVD- and CD-Jukeboxes. The data are available via AutoDRM and Internet (www.szgrf.bgr.de) with a delay between a few minutes and one day. All detected local, regional and teleseismic seismic events are manually analysed on a daily basis. For regional events at the border and outside of Germany, waveform data of GEOFON, Austria, Switzerland, Czech Republic and Denmark are used for routine data analysis. Those data which are not available on Seedlink connections are copied via AutoDRM within a few minutes. Analysed source parameters are stored in a database and distributed to national and international data centres (EMSC, NEIC, ISC). The homepage of the SZGRF (www.szgrf.bgr.de) allows interactive requests to this database.

### BULGARIAN SEISMOLOGICAL NETWORK - CURRENT STATUS – ID 1766

*L. Christoskov, Geophysical Institute, Bulgaria*
*D. Solakov, Geophysical Institute, Bulgaria*
*S. Simeonova, Geophysical Institute, Bulgaria*
*S. Nikolova, Geophysical Institute, Bulgaria*
*L. Dimitrova, Geophysical Institute, Bulgaria*

Seismological observations on the territory of Bulgaria have traditions of more than 100 years. The first seismic station was established in Sofia in 1905. The Bulgarian seismological network-NOTSSI was founded at the end of 1980. Now the network consists of 21 stations. The data from all stations are transmitted in real time to the Seismic Center in the Geophysical Institute. NOTSSI is the only organization in Bulgaria in charge of acquisition of seismological information and is the national information center of rapid earthquake information and seismic hazard mitigation.. Modernization of the NOTSSI started in 1996. Station Vitosha was included in the MEDNET project and was upgraded with STS-1 and Quanterra 380. In 2004, two GURALP-40T BB seismometers with Q330 data acquisition system were put in operation. This upgrading was done in close consultation with ORFEUS and the MEREDIAN consortium members INGV, Roma, Italy and GFZ, Germany. The EC project MEREDIAN-2 (2003-3005) involves NOTSSI in a broadband European network. At the end of 2005, the overall modernization of NOTSSI was done. The upgraded network now consists of 14 stations equipped with 11 REF TEK and 3 Quanterra recorders. Real-time data acquisition is performed using REFTEK's full-duplex error-correction protocol RTPD. The real-time Quanterra data are fed into RTPD via SeisComp/SeedLink protocol. Real-time and interactive data processing is performed by the Seismic Network Data Processor software package. Network command/control and monitoring are performed by RTCC and RTPMonitor. Both RTCC and RTPMonitor serve up html pages that can be displayed in any standard web browser allowing the end-user to monitor the network

status and control the acquisition parameters from any computer connected to the Internet. After modernization, NOTSSI became a world-class digital network providing reliable real-time seismic monitoring and rapid earthquake information to both scientific communities and authorities in Bulgaria.

### 3D FD MODELLING OF LOCAL EFFECTS FOR VALCO S. PAOLO, ROME, ITALY – ID 1775

*I. Oprsal, Charles University, Czech Republic*
*A. Caserta, Isituto Nazionale di Geofisica e Vulcanologia, Italy*
*F. Marra, Isituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Rovelli, Isituto Nazionale di Geofisica e Vulcanologia, Italy*
*J. Zahradnik, Charles University, Czech Republic*

The site of our interest ( 4km x 3km) is situated in the southern part of the city close to the S. Paolo Cathedral including the 3d seismic array located near the third University of Rome. The site shows a pronounced topography that is underlain by middle Pleistocene Volcanic deposits over a Pliocen layer. In the middle the site is characterized by the main sedimentary body of the city: the Tiber valley including an its tributary valley called Fosso di Tor Carbone. Both valleys are filled with Recent Alluvium. Because of that, site effects due to the complex geology and topography are expected. The studied earthquake with a known recording is the Anzio event (M0=1.70e+23 dyne/cm, Mw=4.8) that had occurred on 22/08/2005 at 12:02:08.86 GMT. The epicenter was located approximately 25 km South of the site at an hypocentral depth of 25 Km. Undoubtedly, the risk in the area is comparable to other parts of Rome, however, because no buildings were present here until about 30-40 years ago, no damages due to earthquakes have been reported so far. We use the 3D finite-difference method (Oprsal and Zahradnik, 2002) combined with the respective source to model the earthquake ground motions. The spectral amplification patterns partially correspond to the combination of topography and underground structure, partially these are in unexpected regions due to the 3D structural (hence wave field) complexity of the site. Potential damage zones are determined by the decomposition of the amplification of spectral acceleration.

### MONITORING AND CHARACTERIZING NATURAL OR MAN-MADE NANOSEISMIC (ML < 0.0) SOURCES FOR ENGINEERING PURPOSES – ID 1800

*G. H. Wust-Bloch, Tel Aviv University, Israel*
*M. Häge, Universität Stuttgart, Germany*
*M. Walter, Universität Stuttgart, Germany*
*M. Joswig, Universität Stuttgart, Germany*

Nanoseismic monitoring techniques (Joswig, 2005) were developed in observational seismology to monitor source processes with very weak energy contents under unfavorable signal-to-noise conditions. These nanoearthquakes (Butler, 2003) could be located until 10 km distance for ML -1.0, or 3 km distance for ML -2.0. The applied monitoring techniques integrate portable sparse arrays for data acquisition, semi-automated pattern recognition schemes on sonograms for detection, and graphical jackknifing for event location. By one single array or Seismic Navigating System (SNS), HypoLine software (Joswig, 2005) can already determine origin time, epicenter, depth, suited half-space vP, and short-distance ML. These techniques provide a low-cost and reliable platform to monitor a series of natural or man-made processes that are of interest to the engineering community. In the case of sinkhole and cavitation activity, it is now possible to monitor subsurface material failures before sinkhole collapse since the discrimination of impact signals is indicative of the maturity of the cavitation process. Internal failure generated by active landslides and unstable rock cliffs can be located in 3-D, delivering a way to monitor their evolution in space and time. In seismic hazard assessment, aftershock series and active faults can be mapped with high accuracy and at very short notice. The system is currently being tested as a control platform for blast activity and for induced seismicity/hydrofracturing monitoring (quarries, mines, tunnels and reservoirs).

### MODERNIZATION OF SEISMIC NETWORKS IN SERBIA AND MACEDONIA - A CONTRIBUTION TO REAL-TIME DATA EXCHANGE IN THE SE EUROPE – ID 1836

*P. Labak, Geophysical Institute, Slovak Academy of Sciences, Slovakia (Slovak Republic)*
*S. Radovanovic, Seismological Survey of Serbia, Yugoslavia*
*L. Pekevski, Seismological Observatory of Republic of Macedonia, Macedonia*
*E. Bystricky, Geophysical Institute, Slovak Academy of Sciences, Slovakia (Slovak Republic)*
*A. Cipciar, Geophysical Institute, Slovak Academy of Sciences, Slovakia (Slovak Republic)*

Serbia and Macedonia are located in the Balkan area - one of the most earthquake prone areas in Europe. However, up to 2004 real-time data exchange and analysis were missing in both countries. On contrary, current development allows data acquisition from seismic stations in significant part of Europe in real-time. Example on European level is the VEBSN network of ORFEUS or the GEVN network of GFZ Potsdam. The VEBSN collects real-time earthquake data from 120 broad-band stations of 21 national seismological networks. Example on regional level is the Regional Virtual Network of Seismic Stations at the Geophysical Institute in Bratislava. Although Slovakia has only 12 seismic stations available in real-time on its territory, the data center in Bratislava collects the data from 60 seismic stations in Central and SE Europe. This includes data exchange of 12 countries and allows increasing detection capability of national networks, accuracy of earthquake localizations and rapid dissemination of the parametric information on earthquakes. Benefit from this is not only for European-Mediterranean Seismological Centre (EMSC), which runs an Earthquake Warning System for potentially damaging earthquakes in the European-Mediterranean region, but also for national authorities responsible for civil protection. Experience of the above given examples was used during the modernization of networks in Serbia and Macedonia. The modernization was performed within the projects Development of Infrastructure for Rapid Earthquake Data Collection and Exchange (DIRECTE and DIRECTE2). The projects were supported by the Slovak government. 8 stations in Serbia and 5 stations in Macedonia were modernized. New data analysis centers were created in Belgrade and Skopje using the packages SesiComP and Autoloc (GFZ Potsdam), Seigram (A. Lomax), Seismic Handler (K. Stammpler) and archiving tools (GPI SAS Bratislava). Both data centers provide data in real-/near-real-time and perform automatic earthquake localizations, which are provided to EMSC and other data centers up to 10 minutes after earthquake occurrence.

### ISOLA GUI - A COMBINED FORTRAN-MATLAB TOOL FOR MOMENT TENSOR INVERSION OF REGIONAL DATA – ID 1881

*E. Sokos, University of Patras, Seismological Laboratory, Greece*
*J. Zahradnik, Charles Univ. Prague, Faculty of Math. and Phys., Czech Republic*

Fortran code ISOLA to retrieve isolated asperities from regional or local waveforms has been developed since 2003. It is based on multiple-point source representation and iterative deconvolution, similar to Kikuchi and Kanamori (1991), but full wavefield is considered, and Green's functions are calculated by the discrete wavenumber method of Bouchon (1981). Moment tensor of subevents is found by least-square minimization of misfit between observed and synthetic waveforms, while position and time of subevents is optimized through grid search. ISOLA GUI, presented here, is a Graphical User Interface developed in Matlab with purpose to combine processing speed of the ISOLA Fortran code with user-friendly Matlab environment. Significant features of ISOLA GUI are efficient data handling, interactive control of the inversion process, and wide options of plotting the results. Method and code have been tested in a number of M 3 to 6.7 events in Greece. The code is documented in a manual, accompanied by a test example, and freely available.

### STUDY OF THE SITE INFLUENCE ON THE STATISTICAL PROPERTIES OF SEISMIC NOISE – ID 1884

*E. Gimeno-Nieves, Universidad de Alicante, Spain*
*J. J. Galiana-Merino, Universidad de Alicante, Spain*
*S. Molina-Palacios, Universidad de Alicante, Spain*

One of the most important lessons learned from the catastrophic earthquakes in the last several decades is that the resulting damage at a site could be affected by the earthquake geology of the site, that is, site effects. The evaluation of site effects is, therefore, one of the key component for preventing and mitigating earthquake disasters. In order to evaluate site effects quantitatively S-wave velocity profiles of sedimentary deposits should be determined down to seismic bedrock. Nevertheless, this is an expensive and time-consuming process. This is the reason why a lot of recent studies suggest different more practical methodologies which are based on ambient noise (microtremor measurements) and can be readily performed on the ground surface. In general, in the majority of these methods, the recorded seismic noise is divided into locally stationary segments before applying any signal processing. In this way, artificial or spurious noise is also selected and not taken into account for the subsequent analysis, and only stationary noise segments are considered. The main objective of this work consists in characterising the different stationary segments of the recorded seismograms by AR process in order to study the time evolution of the noise characteristics at different sites. For this task, we have developed an algorithm for selecting automatically stationary noise segments and modelling each one as an AR process. This method allows us to discern better the noise segments that should be used for analysing the site effects. Moreover, the AR modelling has been accomplished in noise recordings from different sites, with different sedimentary characteristics, which also allows us to associate different AR processes with different kind of soils. The measurements were registered at different places of the city of Oslo (Norway), each one with different and known sedimentary characteristics.

### ADVANCE DIGITAL SEISMIC NETWORK FOR EARTHQUAKE HAZARD MITIGATION IN BULGARIA – ID 1915

*S. Nikolova, Geophysical Institute, Bulgaria*
*D. Solakov, Geophysical Institute, Bulgaria*
*P. Passmore, Refraction Technology, Inc., United States*
*L. Zimakov, Refraction Technology, Inc., United States*
*M. Rozhkov, SYNAPSE Science Center, Russian Federation*
*L. Khaikin, SYNAPSE Science Center, Russian Federation*

In December 2005 an advanced digital seismic network supplied by REF TEK was installed to upgrade NOTSSI. The upgraded national network now constitutes of 13 stations: 10 stations equipped with REF TEK 130-01/3 High Resolution Seismic Recorder, two with Quanterra Q330, and one with Quanterra Q380. All 13 digital stations are equipped with 8 broadband, 3 short-period and 2 VBB seismometers. The data from 13 stations are transferred to the CDCA using the VPN and MAN network of the Bulgarian Telecommunication Company via REF TEK error-correction protocol (RTPD) and SeisComp/SeedLink. Data are collected on two SUN Fire V240 Servers, data processing is performed on two SUN Blade 1500 Workstations. Real-time event detection and data processing is performed by SYNAPSE Seismic Network Data Processor (SNDP) software provided by REF TEK. The installed network hardware and software are scalable to any expansion and allow for receive and exchange data in real-time from other networks around the world. Detailed network configuration, data acquisition, processing and exchange are discussed.

### VIRTUAL NETWORK OF THE GEOPHYSICAL INSTITUTE, PRAGUE AND THE QUALITY CONTROL OF DATA – ID 1924

*J. Zedník, Geophysical Institute AS CR, Czech Republic*
*B. Ružek, Geophysical Institute AS CR, Czech Republic*

Virtual network of the Geophysical Institute of the Academy of Sciences of the Czech Republic (GI-ASCR) consists of seven seismological stations operated by the GI-ASCR, and of more than 40 European broadband stations run by cooperating institutions (IPE Brno, GI-SAS Bratislava, ZAMG Vienna, INGV Rome, GFZ Potsdam, SZGRF Erlangen, IG-PAS Warsaw, GSS Ljubljana, NIEP Bucharest, and others). The extensive international cooperation was established within the EC-project MEREDIAN (2000-2005) coordinated by the ORFEUS Data Center and enabled to improve considerably the accuracy of locations of tectonic events and mining-induced shocks in central Europe. Seismicity maps for years 1998-2005 demonstrate also the increased number of located events. Of special attention is the quality control of digital data provided by the Geophysical Institute. The digital archive of the GI-ASCR contains continuous data since 2000. Data are offered in different ways (Antelope and SeedLink packages, Web request form, AutoDRM). Several changes in the instrumentation of stations occurred during their operation. The mutual consistency between station calibration information and digital records is of principal importance. Therefore the consistency test was made using the microseismic noise as a source of calibration signal. It is shown in the poster that the level of microseismic noise is stationary provided convenient processing and averaging is applied. Both short-term and long-term variations are coherent across the network. Anomalous behavior indicates incorrectly applied calibration. Our method is similar to that used in the ORFEUS Data Center.

### AUTOMATIC SEISMIC PHASE PICKING AND WEIGHTING: HIGH-QUALITY APPLICATIONS IN EUROPE – ID 1933

*F. Aldersons, Scientific consultant, Switzerland*
*R. Di Stefano, INGV, Italy*
*T. Diehl, ETH, Switzerland*
*E. Kissling, ETH, Switzerland*

In order to improve the consistency of seismic phases at national and European scales, single-trace automatic picking methods can be used at some stage. Despite the abundant literature devoted to automatic phase picking methods, the critical and difficult problem of automatically estimating picking uncertainties is left unsolved by the vast majority of picking algorithms currently in existence.

The picking system MannekenPix (MPX), however, includes an advanced weighting engine rigorously calibrated on reference picks and true uncertainty classes provided by the user. For every automatic phase pick, the weighting engine of MPX attempts to predict the same true uncertainty class as the one that would be estimated by an expert seismologist. As such and as a whole, MPX acts as a consistent extension of manual picking and not as a totally new method possibly in conflict with the legacy of standard seismological practice.

The application of MPX to the very large database of seismograms recorded in Italy between 1988 and 2002 has yielded 81,256 P-picks and related picking uncertainties from about 7,878 well-constrained events. MPX arrival times, picking weights and polarities are very consistent and could substitute bulletin data. Results suggest that 1-D locations and in particular hypocentral depths derived from MPX arrival times are more reliable than those derived from INGV bulletin data. The use of MPX allowed also to enhance the resolution and the depth range of P-wave traveltime tomographic studies performed at the scale of the entire Italian peninsula.

We present also automatic picking results derived from a large database of local earthquakes recorded by regional, national and temporary networks operating within the Alpine region. The main goal of this project is to improve the knowledge of Alpine lithosphere through 3-D traveltime tomography from S-waves.

### A SHORT HISTORY OF SEISMOGEOGRAPHICAL REGIONALISATION – ID 2009

*J. Young, ISC, UK*

Regionalisation in Seismology dates back to the 1940s when Gutenberg and Richter subdivided the Earth into 51 regions according to the seismicity known at the time in any particular area. In the 1960s Flinn and Engdahl took Gutenberg and Richter's seismic regions and with some adjustments subdivided these regions into 728 smaller regions which they called geographical regions. With the emergence of Plate Tectonics and with experience using this regionalisation (known as the F-E Code) by the 1980s it was agreed some changes and corrections were required. By the early 1990s it was also decided that the F-E Code was perhaps too coarse for local seismogeographical regionalisation and that this further subdivision would not be based on it. The revised F-E Code with 28 additional geographical regions was published in 1996 becoming the new standard. Local seismogeographical regionalisation in Europe was started in 1994 and should be completed soon.

### WARAN - A MOBILE WIRELESS ARRAY ANALYSIS SYSTEM FOR IN-FIELD AMBIENT VIBRATION DISPERSION CURVE ESTIMATION – ID 2017

*M. Ohrnberger, Institute of Geosciences, University of Potsdam, Germany*
*D. Vollmer, Institute of Geosciences, University of Potsdam, Germany*
*F. Scherbaum, Institute of Geosciences, University of Potsdam, Germany*

In the realm of near surface shear velocity profiling for site effect prediction the analysis of ambient vibration wavefields by array methods is considered an attractive approach due to its applicability in urban areas. The primary source of information for deriving shallow shear wave velocity models is the estimation of surface wave dispersion curves by means of frequency wavenumber or spatial autocorrelation techniques. For obtaining highly reliable shear wave velocity profiles, it is a key requirement to provide accurate phase velocity estimates for the broadest observable wavelength range in order to reduce model ambiguities in the nonlinear inversion process. However, given the economical and logistical constraints for array experiments (especialy in urban areas), the number of sensors that can be used is restricted. The resulting coarse spatial sampling of the microtremor wavefield does therefore not permit to cover the required broad wavelength range using a single array layout. Iterative measurement strategies using a number of arrays with varying apertures are then required to resolve the trade-off between feasibility of experimental setups and quality of dispersion curve estimates. Unfortunately, the lack of a priori information regarding the observable wavelength ranges for a particular site of interest makes it usually difficult to optimize array setups for iterative deployments. Instead of deploying array rather blindly, it is desirable to use the increasing amount of information acquired during the course of field measurements for a direct control of appropriate array geometries for subsequent deployments. In order to allow such a measurement strategy we have developed a wireless mobile array system which enables the operator to process the recorded data in quasi-realtime using competing array analysis techniques. This information can be immediately used for improved array design, enhanced dispersion curve measures over large wavelength ranges and iterative velocity model inversion.

### THE SIL-SYSTEM - 15 YEARS OF NEAR-REAL TIME MONITORING. – ID 2039

*S. S. Jakobsdóttir, Icelandic Meteorological Office, Iceland*

The SIL earthquake data acquisition and monitoring system has been running in automatic mode in Iceland since May 1991. During these 15 years the network has grown from 8 stations in South Iceland Lowland to 49 stations spread over the country and it is still growing. Beside locating and estimating magnitudes of earthquakes down to magnitude -1, fault planes and focal mechanism is automatically calculated for almost all recorded earthquakes. An automatic alert system works on the automatic list of earthquakes, using SMS and the audio devices of the work stations to alert the staff at the Icelandic Meteorological Office of changes in seismicity. Some 250.000 earthquakes have been recorded by the system, the largest of magnitude 6,6. Also 5 volcanic eruptions have been monitored since 1991. The high quality data collected by the system has been the basis for several European research project aiming at developing methods for earthquake prediction. Some of these methods are now being implemented to the system to help monitoring critical changes in the seismic pattern.

### CALIBRATION EXPLOSIONS IN ISRAEL, CYPRUS AND JORDAN FOR CTBT MONITORING – ID 2044

*Y. Gitterman, Geophysical Institute of Israel, Israel*
*R. Hofstetter, Institute of Israel, Israel*
*V. Pinsky, Institute of Israel, Israel*
*K. Solomi, Geological Survey Department, Cyprus*
*A. Q. Amrat, Natural Resources Authority, Jordan*

Large-scale calibration underwater and in-land explosions were conducted recently in Israel, Cyprus and Jordan. The experiments were realized in the context of the CTBT monitoring in the Middle East, and aimed to improve the velocity models for calculating travel times to regional and IMS stations; to extend Ground Truth (GT0) database. The GII conducted a series of large blasts at Rotem phosphate quarry in May 2002. The main 25-ton explosion of special design (near-spherical charges in 27 boreholes) yielded magnitude ML 3.0. The event was recorded in a broad distance range 0.3-450 km, providing data complementary to the closely spaced Dead Sea shots (1999). Unique experiment was conducted in 2003 jointly by GSD and GII in the diabase massive. Tests 0.3 and 2 tons were detonated in a deep ( 200 m) borehole full of water. Local magnitude of the event was lower ML 2 than expected. The rapid energy attenuation was explained by signal high-frequency, observed at close BB station CSS ( 20Hz at 10 km). Explosion series was realized by GII in June 2004 in Sayarim, in boreholes of large diameter, providing data for yield-dependent analysis of waveforms up to 400 km. Coda-derived moment-rate spectra technique was applied to BB records for determination of stable regional magnitude. Significant seismic strength was achieved (ML 3 for the largest shot 32.5 tons) in spite of charge accommodation in dry alluvium, and shallow burial depth, commonly considered as low-coupling factors. The NRA conducted recently two single-fired explosions at Ruwayshid (40 tons) and Eshidiya (20 tons), Jordan. The explosion design was similar to the Sayarim experiment. Clear regional phases Pn, Pg and Sg were found at stations up to 400 km. Obtained network and array observations were used for joint location analysis of the explosions, based on up-to-date algorithms and software developed in GII and GT0 data.

### EARTHQUAKE SEISMOLOGY IN GREENLAND - NEW DAA, MULTIPLE APPLICATIONS – ID 2080

*T. B. Larsen, Geological Survey of Denmark and Greenland, Denmark*
*P. Voss, Geological Survey of Denmark and Greenland, Denmark*
*S. Gregersen, Geological Survey of Denmark and Greenland, Denmark*
*W. Hanka, Geo-ForschungZentrum, Germany*
*T. M. Jorgensen, Geological Survey of Denmark and Greenland, Denmark*
*O. Gudmundsson, University of Island, Iceland*
*T. Dahl-Jensen, Geological Survey of Denmark and Greenland, Denmark*

Almost every year new temporary BB seismographs are installed in Greenland in connection with a research project. The first permanent BB seismograph in Greenland was installed jointly by GEOFON, IRIS and Danish seismologists at Kangerlussuaq (SFJD) in 1996. In the ten years that have passed, a total of 29 different locations in Greenland have been equipped with BB sensors for shorter or longer periods of time. Four of the seismograph stations are permanent, and several are semi-permanent. Currently 14 BB seismographs are operating in Greenland, mainly along the coasts. One of the seismographs is located at the Summit ice camp in central Greenland.

The data are utilised in many different ways. Structural studies have been the focus for most of the deployments, and both receiver function (RF) analysis and surface wave tomography have proven effective in obtaining first order models for crust and upper mantle. Every time a BB seismograph has collected enough data at a new location, RF analysis is performed to obtain the depth to Moho. Even this basic parameter is unknown in large parts of Greenland.

The improved seismograph coverage of Greenland also enhances our knowledge of the local seismicity. The epicentres for local earthquakes can be determined much more accurately than before, enabling us to make connections to local geological structures, and to obtain a better understanding of the regional stresses. Recently the BB data from Greenland have found a new application in the study of glacial earthquakes. A large field campaign involving GPS-instruments will take place on an East-Greenland glacier during the summer of 2006 to study the glacial earthquakes in more detail.

## SC-B 2: The 20th Century Strong Euro-Mediterranean Earthquakes from Historical Seismograms

Level 2

### PRESERVING LEGACY HISTORICAL EARTHQUAKE DATA IN TURKEY – ID 314

*N. Meral Ozel, Kandilli Observatory&ERI,Bogazici Univ.Geophys, Turkey*
*A. Berberoglu, Kandilli Observatory&ERI,Bogazici Univ.NEMC., Turkey*
*F. Bekler, Kandilli Observatory&ERI,Bogazici Univ.NEMC., Turkey*
*M. Kara, Kandilli Observatory&ERI,Bogazici Univ.NEMC., Turkey*
*D. Kalafat, Kandilli Observatory&ERI,Bogazici Univ.NEMC., Turkey*

In Turkey, many large and moderate-sized earthquakes that occurred in the past, before the installation of a large number of continuously recording high-tech seismic stations, were recorded only on paper, film or analog tapes by a variety of old type of instruments. KOERI have been monitoring seismic activity since 1926 and had quite a rich data of historic earthquakes. Unfortunately, those data are not well preserved and properly archived. These earthquakes mostly have been recorded on smoked, ink, photographic and heat sensitive papers by mechanical type of seismographs. Because of damage caused by natural reasons such as attacks from insect and animals, micro-organisms, oxidation of the paper, careless handling, tearing, pollution, light, humidity, seismograms had undergone danger of annihilation. In March 2005, we set up a project entitled "Legacy Data Rescue Project" for migrating these legacy data on to successive digital format. This project is being supported financially by Bogazici University Research Fund. The aim of this project is not only to transfer historical data into digital form but also cataloging, re-arranging and conservation of these original records together with their related paper documentation. We have been collaborating with the working group of Euroseismos project to improve the cooperation between seismologists, and to evaluate the historical heritage of observations of earthquakes. Historical earthquakes of Turkey are already included in the list of European earthquakes, and distributed among the partners to collect the additional Turkish data recorded by neighboring European countries. We have already collected more than 400 old records, and 374 of them have been digitized by Sismos scansion Laboratory with very high resolution scanner (1016 dpi, Eskoscan 2636). For the time being, digital raster images are available on a register-user web site for the project partners only.

### SEISMIC MOMENT OF THE MAY 28TH 1943 MW=5.4 ONSTMETTINGEN (GERMANY) EARTHQUAKE WITH MOMENT TENSOR INVERSION – ID 1909

*F. Bernardi, INGV, Italy*
*B. Palombo, INGV, Italy*

The technical facilities introduced by the Sismos and Euroseismos projects allow now to apply modern methods of digital-data analysis for the earthquakes recorded by mechanical and electromagnetic seismographs. Thus, we propose to estimate the seismic moment Mo with moment tensor inversion by means of full seismogram spectra amplitudes. Generally, the sensitivity of mechanical and electromagnetic seismographs is restricted to a 1 s <= T <= 30 s period band. This small period band requires the use of calibrated earth-models, that are often not available, to compute the kernels. Since spectra amplitudes are less sensitive to the crust and upper mantle heterogeneity than phase velocities, we can apply a global 1D earth model to compute the kernels. We thus expect to retrieve stable and reliable Mo estimates with our method. Particularly, we have applied this method to the Mw=5.4 Onstmettingen (Germany) earthquake of May 28th, 1943. For this event, we have collected non-saturated seismograms with a good signal-to-noise ratio from 11 stations, azimuthally well distributed in Europe. An independent Mo = 8.98 ·10e15 Nm estimation from calibrated surface wave amplitudes already exists for this earthquake. Additionally, we have also computed Mo with the Brune Formula, which was successfully applied to pre-digital data in the past. Finally, these two Mo estimates have validated our method.

### ANDRIJA MOHOROVICIC MEMORIAL ROOMS – ID 1914

*M. Herak, Faculty of Science, Department of Geophysics, Croatia (Local Name: Hrvatska)*
*D. Herak, Faculty of Science, Department of Geophysics, Croatia (Local Name: Hrvatska)*
*I. Allegretti, Faculty of Science, Department of Geophysics, Croatia (Local Name: Hrvatska)*

The memorial rooms of renowned geophysicist Andrija Mohorovicic were opened at the Department of Geophysics (Faculty of Science, University of Zagreb) on 9 November 2005, exactly 125 years from the great Zagreb earthquake. On this occasion we also marked 100th anniversary of the Zagreb seismological observatory, 95th anniversary of the discovery of the Mohorovicic discontinuity and 70 years since Mohorovicic's death. Mohorovicic started his career as a meteorologist, first in Bakar, and afterwards in Meteorological observatory in Zagreb, of which he became a director in 1892. At the turn of the centuries, his scientific interest turned to seismology in which he earned his international reputation. Analysing the Kupa valley earthquake of 8 October 1909 he was able to prove the existence of the thin boundary layer between the Earth's crust and mantle, later called after him the Mohorovicic discontinuity. This is without any doubt the most important scientific discovery ever published in a Croatian journal. Some of his ideas were truly visionary – e.g. effects of earthquakes on buildings, harvesting the wind energy, hail suppression, models of Earth and atmosphere. Mohorovicic is today recognized not only as the founder of Croatian seismology, but also as initiator of Croatian meteorological and time-keeping services. One Moon crater and one asteroid were named in his honor. The two memorial rooms hold exhibits related to Mohorovicic's life, and his scientific and professional work. They include original documents (letters, manuscripts, computations, reports, notebooks, travel-time charts...), publications, furniture and original instruments – all restored and in working condition! The most valuable exhibits are the Sprung-Fuess microbarograph (1903 – one of the few remaining in the world), the passage-instrument (prior to 1892), a collection of observatory clocks and chronographs, and three Wiechert seismographs – horizontal instruments of 80 and 1000 kg (1908 and 1909, respectively) and a vertical one (1200 kg).

### A REEVALUATION OF THE JULY 18, 1934 PANAMA EARTHQUAKE THROUGH THE USE OF HISTORICAL SEISMOGRAMS – ID 1977

*E. Camacho, Instituto de Geociencias, Universidad de Panama, Panama*
*R. Macià, Dept. Matemàtica Aplicada II, UPC, Spain*
*J. Batlló, Observatori de l'Ebre. CSIC - URL, Spain*
*D. Stich, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

At the southwestern margin of the Isthmus of Panama, the Cocos, Nazca and the Panama Microplate join in a triple junction. Here the Panama Fracture Zone which acts as the limit between the Nazca and Cocos plate, subducts in an oblique and shallow manner. This is one of the most active seismic regions of Central America. On July 18, 1934 here occurred a major event (Ms 7.7), which is considered the largest earthquake occurred in Panama during the XX Century. It originated in the northern terminus of the Panama Fracture Zone and caused extensive damage in the border region of Panama and Costa Rica. In the two subsequent days six aftershocks greater than 6.0, were recorded.

Due to the fact that in this region is being planned to built a major regional oil refinery and petrochemical installations and one third of the population of Panama and one fourth of Costa Rica lives here, it is important to understand the seismotectonics of this region an how big seismic series like this may develop.

Event though this event has been studied before, the interest has always focus on the main event. We have been collecting and digitizing historical seismograms to determine the moment tensor and CMT from the main event and its major aftershocks. Additionally we will gather new macroseismic information, to create an improved and more complete isoseismal map of this event.

Many of the collected records have been gathered from the EUROSEISMOS database, due to the fact that the studied event occurred in the same date of one of the EUROSEISMOS events. This coincidence allows us to show further applications of EUROSEISMOS and possible ways of further developments of the project.

The present status of this research project on the July 1934 series of earthquakes in Panama and further developments are presented here.

### MACROSEISMIC EFFECTS OF THE 23 APRIL 1909 EARTHQUAKE NEAR BENAVENTE (PORTUGAL) – ID 1980

*J. Batlló, Observatori de l'Ebre. CSIC - URL, Spain*
*B. Palombo, Istituto Nazionale di Geofisica e Vulcanismo, Italy*
*P. Teves-Costa, Centro de Geofisica da Univ. de Lisboa e DF-FCUL, Portugal*

The 23 April 1909 earthquake, with epicentre near Benavente, has been the largest surface earthquake (Ms=6.3) in the Iberian Peninsula during the 20th century. Due to its importance, several studies, both in Portugal and Spain, were developed soon after its occurrence, compiling and describing its effects. Other studies have been performed in the last years, mainly concerning its source parameters, recognizing again its importance. As a result of these studies seismic moment, focal mechanism and other parameters related to earthquake focus and obtained from instrumental records of this earthquake have been reviewed and recalculated.

Recently, the macroseismic field of this earthquake has been also reviewed. Felt intensities all over the Iberian Peninsula have been reviewed and reassigned. The new database contains more than 475 intensity data points for this event. This poses a good opportunity to recalculate focal parameters from the macroseismic field using "boxer" tool. Obtained results are compared with the previously obtained parameters from instrumental data showing good agreement and give interesting indications on how to use this methodology for a further analysis of the large earthquakes occurred in the Iberian Peninsula in old times.

The large amount of seismograms, station bulletins and macroseismic data collected for this earthquake, as well as the results of previous studies about it poses a unique opportunity to combine all of them for the accurate determination of its epicentre. Lomax algorithm for earthquake location has been run using as much seismic phases as possible and the results tested against previous results, obtained with other algorithms, and macroseismic determinations. The obtained results point new ways to use old bulletin data and seismograms for epicentre determination.

### ON THE 20TH CENTURY'S STRONGEST WESTERN ROMANIAN EARTHQUAKES: PRELIMINARY RESULTS FROM THE EUROSEISMOS PROJECT. – ID 1991

*M. Caciagli, SGA - Storia Geofisica Ambiente., Italy*
*E. Oros, NIEP Romania, Timisoara Seismological Observatory., Romania*

The state-of-the-art on the several earthquakes that affected western Romania during the first part of the last century, is mainly based on macroseismic data with very uncertain intensity data points. At times magnitude and epicentral coordinates have been determined from historical catalogues (e.g. Karnik, 1968). The main events that occurred in the region are also present in the list of earthquakes included in the EuroSeismos project (http://storing.ingv.it/es_web). For this study we chose, on the basis of the degree of damage documented at the epicentral areas, the 9th – 27th October 1915 seismic sequence with a main shock of the 19th October at 08:43:54 GMT (Io=VII-VIII MSK), the earthquake on 6th September 1936 at 4:49:02 GMT (Io=VII MSK), the 30th August 1941 at 4:41:44 GMT event, the earthquakes on 27th May 1959 at 20:38:26 GMT (Io=VII-VIII MSK) and 22nd October 1960 at 19:17:48 GMT (Io=VI MSK). The large number of the seismograms obtained from many seismic stations and the seismic bulletins of the EuroSeismos project have offered the opportunity to study and review the parameters of all these events on an instrumental data basis. Up to now, 27 seismograms have been collected for the 1915 seismic sequence, 40 seismograms for the 1936 event, 41 seismograms for the 1941 event, 71 seismograms for the 1959 event and 30 seismograms for the 1960 event. After a vectorialization with Teseo software (http://sismos.ingv.it/teseo/) and a necessary signal correction on the base of instrumental constants of different historical seismographs, it has been possible to obtain a reassessment of the main seismological parameters of the events. An initial comparison between these parameters and the same ones extrapolated from the macroseismic data and from previous studies, are described here.

### RESTORATION AND CONSERVATION OF SEISMOGRAMS: THE EXPERIENCE IN THE EUROSEISMOS PROJECT – ID 2010

*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*
*C. Roversi Monaco, Italy*

Over the last twenty years, the historical documentation of seismology has been acquiring increasing importance in the scientific interpretation of historical earthquakes. As seismology cannot reproduce the experiments observed in the laboratory, unlike other disciplines such as physics or chemistry, the historical seismograms and their related documentation play a fundamental role in the study of the strong earthquakes of the past 100 years at least. Various factors have often determined the dispersion, the destruction or the poor conservation of historical seismograms. An observatory equipped with numerous instruments and a long research tradition often finds itself having to deal with thousands of seismograms reproduced on different media: smoked paper, photographic paper, etc.. The people responsible for managing these seismogram archives are facing a growing demand for these recordings and at the same time have to deal with the broader and more complex issue of how the seismograms ought to be properly preserved. The recent experiences performed experimentally within the framework of the EuroSeismos project have allowed us to focus on some of these issues, as we have sought to provide solutions and general methodological guidelines to resolve in an economically feasible as well as acceptable way the most pressing problems in the recovery and conservation of historical seismograms and their related historical documentation. We present our experience with over 25,000 seismograms, all of different kinds, coming

from numerous observatories situated in the Euro-Mediterranean countries, over 1,000 of them have been restored.

## SC-D 0: Crust and Upper Mantle Structures (Open Session – Posters Only)

Level 2

### PASSIVE SEISMIC MONITORING EXPERIMENT IN THE DINARIDES-PANNONIAN SECTION ALPASS-DIPS – ID 524

*A. C. Kovacs, ELGI, Hungary*
*F. Sumanovac, Zagreb University, Croatia (Local Name: Hrvatska)*
*E. Brückl, TU, Austria*
*Z. Hajnal, USASK, Canada*
*E. Hegedus, ELGI, Hungary*
*G. Houseman, University of Leeds, UK*
*G. Stuart, University of Leeds, UK*
*R. Keller, UTEP, United States*
*R. Csabafi, ELGI, Hungary*
*J. Oreskovic, Zagreb Univerity, Croatia (Local Name: Hrvatska)*

The CELEBRATION 2000 and ALP 2002 wide-angle refraction and reflection experiments covered the Eastern Alps, Dinarides and Pannonian area with several profiles.The data provided the shape of the Moho and details of the crustal structure. In the frame of the ALPASS program 80 passive seismic recording stations have been deployed for the period of May 2005 and May 2006. Further 15 stations have extended this grid along Alp 07 profile connecting the Adriatic region (Istria) and West Pannonia for two years period. Data will be evaluated together with the contemporary Carpathian Basins Project by receiver function analysis, teleseismic P-wave and surface-wave tomography. In order to enhance the accuracy of the above methods, a detailed P-wave velocity model of the crust derived from the previous active source experiments will be utilized. Samples of data and preliminary results will be presented.

### PRELIMINARY RESULTS ON SHALLOW EARTHQUAKE SIMULATION FOR THE SOUTHWESTERN PART OF THE HELLENIC ARC – ID 564

*E. Kokinou, Technological and Educational Institute Crete, Greece*
*F. Vallianatos, Technological and Educational Institute Crete, Greece*
*E. Bouranta, Technological and Educational Institute Crete, Greece*

Main purpose of the present study is the simulation of ground motion evoked by shallow earthquakes in high complex areas such as the southwestern part of the Hellenic arc in the wide area of Crete Island (Greece). The modelling of P and S arrivals at near and middle source distances is based on Kennett's reflectivity method. Point source is considered in the present modelling effort, located in the middle of fault. The seismic response to the point moment tensor source is built up from the reflection and transmission properties of portions of the media in the frequency – slowness domain. This allows control of the propagation processes in the shallower parts of the model considered. The P wave velocity model for the upper crust is based on streamer reflection experiments in offshore area around Crete Island. The vertical heterogeneity of the upper crust in the study area is approached by dividing every layer of the known velocity model in a distinct number of sub-layers. The 24 July 2004, mb = 4.6 (Harvard Solutions) earthquake characteristics are considered in our simulations. N-S striking normal faulting is possibly responsible for the above earthquake. The calculation scheme provides a good representation of the main P and S arrivals at near and middle distances and can be used for both source and crust studies.

This work is supported by the project ARCHIMEDES I: "Support of Research Teams of Technological Educational Institute of Crete", sub-project entitled "Multidisciplinary Seismic Hazard monitoring in the Front of the Hellenic Arc " in the framework of the Operational Programme for Education and Initial Vocational Training. The authors express their gratitude to HELLENIC PETROLEUM Co. (EL.PE) for the seismic data availability and Dr. Kennett B. L. N. for the plotting routine.

### CRUSTAL VELOCITY MODELS FOR THE WIDE AREA OF CRETE ISLAND IN THE SOUTHERN HELLENIC SUBDUCTION ZONE – ID 577

*E. Kokinou, Geophysics Dep. Aristotle University, Greece*
*E. Papadimitriou, Geophysics Dep. Aristotle University, Greece*
*V. Karakostas, Geophysics Dep. Aristotle University, Greece*
*F. Vallianatos, Technological and Educational Institute Crete, Greece*

The Hellenic Subduction Zone consuming the remnants of Tethyan seafloor is subducting northward beneath Crete Island as part of the eastern Mediterranean oceanic lithosphere in contact with the northward moving African continental plate. Crete is located in the forearc of the Hellenic Subduction Zone. The north-dipping Wadati-Benioff seismic zone is extending beneath Crete to a depth of about 200 Km. Nowadays the Hellenic arc is associated with moderate arc-pararell extension and strong compression perpendicular to it. The Hellenic nappes are the dominating sequences within the upper structure of Crete Island. Two major rock successions could be distinguished, the pre-Neogene rock succession and the Neogene rock succession. The largest earthquakes occurred on and around Crete indicate E-W extension along N-S striking faults onshore Crete. N-S extension dominates the offshore regions south of Central and Western Crete, while normal and thrust faulting is the predominant mechanism south of Eastern Crete. Information concerning deep onshore and offshore seismic reflection experiments data, topographic data and bibliography was used in order to construct detailed velocity models for the area around Crete Island and trace the main sedimentary sequences as well as deeper structures.

This work is supported by the project PYTHAGORAS - E.P.E.A.E.K. II (project title: Seismotectonic and Geodynamic Attributes of the Southern Part of the Hellenic Arc). The authors express their gratitude to HELLENIC PETROLEUM Co. (EL.PE) for the seismic data availability.

### 1-D MODELS FOR Q-FACTOR IN THE CRUST IN THE VRANCEA REGION (ROMANIA) – ID 1649

*L. A. Ardeleanu, National Institute for Earth Physics, Romania*

The complex structure in the Vrancea region (Romania) is due to its particular location, at the contact of 4 tectonic units: the Eastern European plate, and the Moesian, Black Sea and Intra-Alpine subplates. An appropriate 3-D inhomogeneous model for the area is still under construction, but 1-D local velocity and density models for various sites are already available. The quality factor of the medium is the less known structural parameter, therefore we propose in the present paper 1-D models for Q, appropriate for various ray paths in the region. The models are estimated by comparing the synthetic waveforms, computed using the multimodal summation method in layered anelastic media, with the high frequency records of low magnitude local earthquakes. The results point out significant lateral variations of the best fitting Q models, indicating high attenuation of the seismic waves in the foredeep region from the bending of the Eastern Carpathians.

### VERTICALLY INHOMOGENEOUS MODELS OF THE UPPER CRUST IN THE AIGION REGION OF GREECE, INFERRED FROM ARRIVAL TIMES – ID 1698

*O. Novotny, Charles University, Fac. of Math. and Phys., Czech Republic*
*H. Lyon-Caen, Ecole Normale Superieure, France*
*J. Jansky, Charles University, Fac. of Math. and Phys., Czech Republic*

*V. Plicka, Charles University, Fac. of Math. and Phys., Czech Republic*

The western part of the Gulf of Corinth attracts attention due to its seismically active fault system and considerable seismic hazard. Detailed studies of the seismic activity of the region have been carried out as part of the so-called Corinth Rift Laboratory (CRL) Project. For standard earthquake locations, the CRL uses the HYPO algorithm and a special structural model. The model was derived from a passive seismic experiment in a broader area around the western part of the gulf. A significant part of the seismic activity is concentrated close to the town of Aigion. A sequence of smaller earthquakes occurred there also in the first half of the year 2001. In the present paper, we have used this sequence to derive local structural models of the Aigion region, composed of homogeneous layers, and to compare them with the CRL model. In particular, we have used arrival times from a sub-set of 133 events that were recorded by at least 6 stations of the southern part of the CRL network, and had magnitudes of over 2.3. A variant of the method of conjugate gradients has been used to derive the models, as well as for locating the hypocentres. Analytical formulae have been derived for the arrival-time partial derivatives, needed in the method. Only models composed of 4 homogeneous layers with velocity increasing with depth have been considered. We present a set of satisfactory models based on the minimization of travel-time residuals. Their velocities are higher than those in the CRL model.

## UPPER CRUSTAL STRUCTURE, FLUIDS AND EARTHQUAKE SWARMS IN THE WEST BOHEMIA/VOGTLAND REGION – ID 1767

*A. Bouskova, IG CAS, Czech Republic*
*E. Faber, GFZ, Germany*
*J. Horalek, IG CAS, Czech Republic*
*Z. Hudová, IG CAS, Czech Republic*

West Bohemia/Vogtland earthquake swarms occur in region with complex tectonics and geological structure. It is intersected with two main fault systems, Eger rift and Mariánské Lázně fault zone, N-S faults were lately described. More than one hundred mineral springs and a few hundred gas vents are located at the intersection of these fault zones. Two Quaternary volcanoes, Komorní Hurka and Železná Hurka, are located in the seismoactive region. Seismic swarms are, generally, associated with active volcanism and geothermal fields. Its origin is usually explained as an interaction of the tectonic stress and high-pressurised crustal fluids in a subcritically loaded rock environment. Evidence of the fluid-triggered swarm earthquakes is also noted from stable tectonic areas, similar to the Western Bohemia/Vogtland area, where some changes of mineral springs and CO2 discharge during seismic swarms were indicated. Seismic network of IG and IRSM CAS with 10 permanent local stations monitor the whole seismically active area. The gas discharge in proximity of main focal zone near Novy Kostel has been measured by the Federal Institute for Geosciences and Natural Resources in Hannover. We discuss possible relations between the earthquake activity, parameters of gas discharge and active faults and subsequently their relationship to seismic waves deviations (azimuthal dependences of P- and S-wave velocities, wave backazimuth deviations).

## ANISOTROPY BENEATH GREENLAND REVEALED BY SHEAR-WAVE SPLITTING – ID 1771

*N. Ucisik, Niels Bohr Institute, Denmark*
*O. Gudmundsson, Institute of Earth Sciences, Iceland*
*W. Hanka, GeoForschungsZentrum, Germany*
*T. Dahl-Jensen, Geological Survey of Denmark and Greenland, Denmark*
*K. Mosegaard, Niels Bohr Institute, Denmark*
*K. Priestley, Bullard Laboratories, UK*

Seismic anisotropy was investigated by measuring shear-wave splitting at 19 broadband stations in Greenland. We examined mostly SKS and SKKS phases. Splitting parameters (fast polarization, fi, and time delay, dt) were determined for these phases. In total, 318 usable phases from 166 events were found at the 19 stations. The number of individual phases used at the various stations ranges from 4 to 56. Uncertainties (1 sigma) range between 1.4°-9.6° and 0.03–0.36 s for fi and dt, respectively.

The fast polarizations at nine sites in southern Greenland are quite uniformly oriented roughly N-NE. Four sites in central Greenland show varying orientations of fast polarization. Three sites in central northern Greenland show a similar geometry to southern Greenland. One site in northern-west Greenland shows no splitting. Two sites in northern Greenland show weak splitting and east-westerly orientation.

Time delays range from 0.4 to 1.4 s and can generally not be explained by crustal anisotropy alone. The lithospheric thickness in Greenland is 100 km. Time delays of up to 1.4 s indicate anisotropy up to 6 % in the lithosphere.

The uniformity of splitting orientations in southern Greenland encompasses a number of structural units, the Ketilidian formation, the Archean core of the continent, and the Nagssugtoqidian and Ammassalik mobile belts on the west and east coast, respectively. Two sites in the Rinkian mobile belt and inland from the Rinkian in central northern Greenland show a similar orientation. This suggests a common source of anisotropy for this region that is not related to the accretion of the individual blocks. The different geometry in northern Greenland suggests that the source process is not currently active. The irregular geometry of splitting in central Greenland may be related to the impact of the Iceland plume at 60 Ma.

Key words: shear-wave splitting, anisotropy, lithosphere, Greenland.

## EFFECTIVE STRESS EVOLUTION DURING GAS-HYDRATE FORMATION IN THE DEPOSITING SEDIMENTS – ID 1795

*E. Suetnova, Inst. of physics Russ. Academy o, Russian Federation*

Effective stress distribution in fluid saturated sediments determines their compaction under the tectonic loading and during the sedimentation. To calculate effective stress evolution through the geological history of sedimentary basin with formation and accumulation of gas-hydrate deposits inside them, the mathematical model was developed. The model is based on Maxwell type rheological visco-elastic low of saturated sediments deformation. The sources of gas can be biogenic or thermogenic origin. The system of governing equations includes momentum equation, conservation of mass equations, heat transfer equation, and fluid flow equation. Deposition of hydrate is determined by P-T conditions and rate of gas-saturated fluids. The boundary conditions include heat and gas flux and fluid saturated sediments deposition. Model calculations show that relatively low effective stress zones distribution strongly connected to the position of gas-hydrate zone for all reasonable value of sedimentation rate. Gas-hydrate accumulation in sediments leads to non-monotonous profile of effective stress along the depth, which could create the formation instability. Study was supported by RFBR grant 06-05-65260-a

## HYDRAULIC OVERPRESSURE GENERATION IN SEDIMENTS, ITS DEPENDENCE ON GAS FLUXES FROM DEPTH – ID 1798

*V. Cherniavski, Inst. of Mechanics, Moscow State University, Russian Federation*
*E. Suetnova, Inst. of the physics of the Earth, Russ. Academy o, Russian Federation*

Sediments compaction during their accumulation and burying may results in overpressure development at medium or great depth of basins. The occurrence of overpressure depends on sedimentation history. But temperature and pressure conditions in growing sedimentary layer often are favorable for forming gas-hydrate in shallow or medium depth. Accumulation of gas-hydrates leads to decreasing of effective porosity and dramatically decreasing permeability. Presented mathematical model of flow in porous media with variable porosity and free surface describes these transient processes. Model calculations show how the overpressure developed in dependence of gas fluxes from depth.

### DSS AND SEISMICITY CATALOGUE HELP TO UNDERSTAND THE LITHOSPHERIC STRUCTURE BENEATH THE ITALIAN PENINSULA – ID 1874

*S. Solarino, Ist. Nazionale di Geofisica e Vulcanologia, CNT, Italy*
*R. Cassinis, Viale Lombardia, 30, Italy*

A further contribution is given to a more detailed knowledge of the crust and upper mantle structure of the Italian region, integrating the results of deep seismic exploration (mainly DSS) with the updated catalogues of seismicity. We projected the recorded hypocenters on vertical cross sections either containing the interpretation of seismic results either along relevant lines parallel or perpendicular to them, adding some information, where available, on the physical characters of the upper lithosphere. The main conclusion of this study is that the earthquakes are generated especially in the upper, rigid crust but also that they concentrate above the lateral discontinuities found by the DSS in the deep crust or at the Moho boundary. However, in four areas along the peninsula (i.e. the western Alps, the northern Apennines, the north-central Apennines and the Calabrian arc) and in one at its border (i.e. the Dinarides) earthquakes are observed also in the upper mantle . Overall, the seismicity is deepening from north to south, where it reaches more than 400 km depth along the slab that guides the subduction of the Ionian plate beneath the Tyrrhenian. Although the computation of magnitude is not complete for the whole catalogue, the available data suggest that the magnitude of deep events seldom exceeds 5.0. The different behavior of deep seismicity in the four areas confirms that the Italian Peninsula is formed of sectors having a different geodynamic history.

### A P-RESIDUAL STUDY OF DEEP STRUCTURAL DIFFERENCES BENEATH SOUTHERN SCANDINAVIA – ID 1893

*A. Bondo, Dept. Earth Sciencen, Denmark*
*N. Balling, Dept. Earth Sciences, Denmark*
*B. H. Jacobsen, Dept. Earth Sciences, Denmark*

Based on P-residuals we study differences in the seismic velocity structures in the mantle lithosphere and asthenosphere in southern Norway and the northern part of Denmark. The study area covers the southwestern part of the Baltic Shield and the southern part of the Scandinavian Caledonides (Southern Norway), the northern part of the Sorgenfrei-Tornquist Zone and the northern part of the Norwegian-Danish Basin. The origin of the Norwegian mountains is still debated, and some of the posed hypotheses have a bearing on expected P-wave residual patterns.

The Sorgenfrei-Tornquist Zone was imaged by the TOR project as a sharp transition between the Baltic Shield in Southern Sweden with a thick lithosphere and the Norwegian-Danish Basin with a thinner lithosphere. A similar transition between Southern Norway and the Norwegian-Danish Basin was indicated by earlier studies of Rayleigh-waves.

The region of Southern Norway is covered by a total of 35 mobile stations (intermediate period as well as broadband stations also used for receiver functions) covering different areas and time intervals between 2002 and 2006. About 15 permanent network stations are also considered. In the northern part of Denmark one permanent station is present, and four mobile stations have so far been deployed during most of 2005 and 2006. Preliminary data analysis shows little difference between southern Norway and northern Denmark. After topographic and crustal corrections relative P-residuals are within $\pm 0.7$s. This is different from observations of the TOR project where a strong localized transition across the Sorgenfrei-Tornquist Zone is observed. Towards northwest the deep transition zone may not follow the near surface expression of the Sorgenfrei-Tornquist Zone.

### CRUSTAL STRUCTURE OF THE WESTERN-CENTRAL ALPS FROM RECEIVER FUNCTIONS – ID 1903

*D. Lombardi, ETH, Switzerland*
*J. Braunmiller, COAS, Oregon State University, United States*
*E. Kissling, ETH, Switzerland*
*D. Giardini, ETH, Switzerland*

A large number of geophysical experiments were carried out to unravel the subduction-collision tectonics and the crustal structure of the Western-Central Alps. Active seismic experiments and local earthquake tomography highlight crustal complexities mainly as P-wave velocities and their variations. A complimentary S-wave velocity model allowing a consistent lithological interpretation is missing so far. The receiver function method, which exploits the S-wave signal generated at impedance contrasts, can constrain crustal and lithospheric scale S-velocity structure. Receiver function complexity for the 60 investigated permanent and temporary stations increases rapidly from the northern foreland to the highly deformed inner Alpine zone. The receiver function complexity correlates with the southeast dipping deep-European structures, mid to upper crustal wedging, and intense over-thrusting deformation caused by collisional shortening. Just south of the Insubric line, we detect the northeast dipping Adriatic Moho. We also provide new constraints on Moho depth in the southwestern Alps where information from controlled-source seismology is sparse. The mean crustal vp/vs ratio varies from low-to-moderate in the Alpine foreland and prealps unit and reaches higher values in the Austroalpine and Penninic realms. The larger values possibly reflect high-grade metamorphism and the presence of oceanic crustal remnants in the domain most strongly affected by the subduction-collision process. Preliminary results of modeling converted phases generated at sedimentary and mid-crust discontinuities will also be presented.

### CRUST AND UPPER MANTLE STRUCTURE OF NORTHERNMOST FENNOSCANDIA – ID 1982

*F. Krueger, Institute of Geosciences, University of Potsdam, Germany*
*J. Schweitzer, NORSAR, Norway*
*Masi Working Group, Norway*

Northern Fennoscandia is characterized by a rapid transition from the newly formed oceanic lithosphere in the North Atlantic and the Arctic ocean in the West, over remnants of the caledonian orogeny, the proterozoic greenstone belts to the archaic material in the East. We use data from two temporary seismometer installations in 1999 and in the years 2001-2004 and data from permanent stations to map the crust and upper mantle structure of northernmost Fennoscandia with passive seismological methods: - P-wave receiver functions were used to image the Moho and the uppermantle discontinuity depths. - S-wave receiver functions were used to image the lithosphere-asthenosphere boundary.

For both data sets a regional average velocity model could be used, which was constructed from surface-wave tomography, seismic refraction profiles, gravity modeling, and traveltime and waveform data of local events.

Crust is thickest in the proterozoic regions with more than 45 km and becomes thinner towards the coast in the West and the craton in the East. Modeling of the receiver functions indicate a sharp crust-mantle transition in the coastal region, smooth transitions in the center and again sharper transitions in the East.

The lithosphere thickness reaches from 150 km in the West to about 250 km beneath the archaic region in the East. The lithosphere-asthenosphere boundary is imaged as a well-defined sharp discontinuity, probably less than 20 km thick with a velocity jump of about 2-3 %. SKS splitting results indicate an imprint of the caledonean collision event on the lithosphere beneath the proterozoic belts.

### DEEP-SOURCE ANISOTROPY REVEALED FROM SHEAR-WAVE SPLITTING RESULTS FROM SOUTHWEST IRELAND – ID 2015

*V. C. Do, Dublin Institute for Advanced Studies, Ireland*
*P. W. Readman, Dublin Institute for Advanced Studies, Ireland*
*B. M. O'Reilly, Dublin Institute for Advanced Studies, Ireland*

The observation of large splitting in shear-wave phases such as SKS/SKKS is usually attributed to upper mantle anisotropy due to a fossilized deformation imprint in the lithosphere, or the influence of asthenospheric flow (or both). Shear-wave splitting measurements have been made on data from up to 23 temporary and two permanent broadband stations in Ireland in order to investigate upper mantle anisotropy that may be related to the Iapetus Suture Zone. Data were selected from about 200 deep and shallow focus earthquakes with epicentral distances of 90-130° and magnitudes Mb > 6.0. Most of the high quality results are from earthquakes in South America and East Asia. Average delay times of about 1.2 s are observed which suggests an anisotropic layer thickness of 80-100 km. Analysis of splitting in Sg and SmS phases from a previous controlled-source experiment in southwest Ireland has confirmed that the crustal contribution to the observed anisotropy is no larger than expected and is not a significant contribution to the overall anisotropy. The SKS-splitting results show an unexpected back-azimuthal variation of fast directions, which suggests that there is a sub-lithospheric source of anisotropy. Events from East Asia show fast polarization directions closely related to the Caledonian/Variscan tectonic fabric indicating that this may be preserved in the mantle lithosphere. However, events from South America give consistently more northerly fast directions that do not appear to carry the signature of the sub-continental lithospheric deformation history. Furthermore, there is no observable alignment of the fast polarization direction with absolute plate motion direction, and so no direct correlation with mantle flow. Results from preliminary modelling based on two-layer anisotropy with contributions from mantle flow and lithospheric deformation do not fit the observed splitting pattern. Hence a more complex origin for the observed anisotropy is required to explain our results.

### CRUSTAL STRUCTURE OF THE VOLCANIC CAMPANIAN AREA (SOUTHERN ITALY) FROM DSS AND TELESEISMIC DATA – ID 2033

*G. Gaudiosi, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*
*G. Alessio, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*
*D. Lobascio, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*
*M. Maistrello, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*
*G. Mele, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*
*G. Musacchio, Istituto Nazionale di Geofisica e Vulcanologia -, Italy*

The Campanian area (southern Italy) is one of the highest-risk volcanic area of the world. Mt. Vesuvius, the Phlegraean Fields and the Ischia Island are active volcanic centers. These volcanoes were built up on a large graben area known as Campanian Plain, bordered by the Tyrrhenian basin and by the Apennine chain. The interpretation of the available observations obtained through active (deep seismic sounding) and passive (teleseismic receiver functions) seismic investigations, allows us to obtain a detailed picture of the crustal structure of the volcanic area. All refraction profiles collected since the early 70's and high resolution onshore and offshore wide-angle-reflection profiles were modelled jointly. The receiver functions technique has been applied to teleseismic events recorded by three-component broadband stations installed in the study area. We used earthquakes occurred within epicentral distances of 30-90 degrees, with minimum magnitude 6.0. The results of the seismic investigations, performed in the area, suggest the presence of strong lateral velocity variations in the crust A Moho depth of about 25 km is obtained beneath the Phlegraean Fields. The Moho deepens asymetrically, both toward the NW and SE edges of the Campanian Plain, down to depths of about 35 km. An intermediate intracrustal interface at a depth ranging between 10 and 13 km is well constrained all over the Campanian area. On the contrary, lateral changes in crustal velocity characterize the surface layers.

### ANALYSIS OF SKS SHEAR-WAVE SPLITTING TO INFER MANTLE ANISOTROPY BELOW CENTRAL EUROPE – ID 2045

*M. Walther, BGR/SZGRF, Germany*
*T. Plenefisch, BGR/SZGRF, Germany*

Seismic anisotropy is a characteristic feature of the upper mantle. It may be caused either by present asthenospheric mantle flow or by frozen signatures of former deformation and stress conditions in the lithosphere. Upper mantle anisotropy can be detected and analysed by shear-wave splitting of distinct wave-types, mainly SKS and SKKS phases, of teleseismic earthquakes in the distance range from about 90 to 130 degrees.

In our work we use data from the German Regional Seismic Network (GRSN), the Graefenberg Array (GRF) and networks of Switzerland, Austria and France. By determination of splitting parameters we are able to identify anisotropic regions and their effect on seismic waves and enables us to interprete the results with respect to tectonics.

Several investigations (e.g. Brechner et al. [1998], Vinnik et al. [1994]) based upon data of the first years of the GRSN (up to 1994) or on subsets of stations and small time spans. The authors found considerable splittings for most of the stations. For some of the stations the direction of the fast axis of the anisotropic mantle material is in agreement with directions of tectonic units, boundaries and stress directions. Others show variations in respect to back azimuth indicating more complex anisotropy conditions (e.g. multi-layer) or the influence of heterogeneities.

Now more than 13 years of continuous seismic data registration of GRSN stations and other networks are available. The number of earthquakes between magnitude 5.0 and 8.4 and adequate distance range is higer than 5.000. By using FK-methods and correlation to the Havard moment-tensor database we selected events with sufficient energy at the studied phases. In our poster we will present this method and some new splitting measurements, compare them to the results of former studies and discuss them with respect to tectonics (mantle flow and stress field of the lithosphere) and two-layer anisotropy models.

## SC-D 1: 2-D and 3-D Crustal Models of Europe

Level 2

### REFINING OF THE LET CRUSTAL STRUCTURE IN THE SOUTHERN TYRRHENIAN REGION, ITALY – ID 1562

*B. Orecchio, Messina University, Italy*

A new, more detailed tomographic inversion of P-wave velocity and Vp/Vs ratio has been performed in the Southern Tyrrhenian region using an updated dataset including 6000 earthquakes recorded at a total of 500 stations and 100 artificial sources fired during DSS surveys. The Simul algorithm by Evans et al. (1994) and the more recent, TomoDD method developed by Zhang and Thurber (2003) have been employed for simultaneous inversions of hypocenter and velocity parameters. Synthetic tests have been performed in order to better check the reliability of the three-dimensional models resulting from application of the respective methods in a region where the seismic network geometry is not optimal. The results of the present study have been compared with the most detailed tomographic model available in the literature (Barberi et al., 2004) for the Southern Tyrrhenian region (grid-spacing of 40km). I obtain an overall improvement of the knowledge of the regional crustal structure compared to Barberi et al's (2004) velocity model, allowing in particular to perform additional, more detailed tomographic inversions in sub-sectors of the studied area characterized by denser seismic activity. Inversion grid spacing reduction to values as small as 5-10km was achieved in crustal sub-volumes underneath Sicily and Calabria.

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### ESTIMATING CRUSTAL THICKNESS IN BELGIUM USING MOHO-REFLECTED WAVES – ID 1703

*E. Sichien, Royal Observatory of Belgium, Belgium*
*T. Camelbeeck, Royal Observatory of Belgium, Belgium*
*J. P. Henriet, Ghent University, Belgium*

We present the first results of the determination of the Moho depth underneath Belgium using reflected P and S-waves (PmP- and SmS-waves). Previous studies suggest differences of the Moho depth in the different parts of the region. In the lower Rhine Embayment in the northeast, the Moho depth is considered to be shallow (25 km). In the Brabant Massif in the west the crustal thickness is supposed to be larger (up to 38 km). The southeast of Belgium is characterised by the Variscan allochtone, where the Moho depth is around 30 km. In this study, PmP/SmS-waves of 130 well-located local earthquakes registered by 37 stations of the permanent seismic network and by mobile stations installed by the Royal Observatory of Belgium were used. More than 370 PmP/SmS-waves were modelled to determine the Moho depth with the following procedure. PmP-arrivals are picked and the locations of the PmP-bounce points are determined and mapped. Over this map a 20 x 20 km grid is placed and for each grid cell an iteration is performed to determine the Moho depth. The thickness of the crust varies between 27 and 34 km and is slightly shallower in the northeast of Belgium (29-30-31 km) than to the southwest (33-34 km). This is in agreement with what should be expected: a shallower Moho depth when approaching the Lower Rhine Embayment and a deeper Moho underneath the Brabant Massif.

### UNCERTAINTIES IN THE INTERPRETATION OF REFLECTION EVENTS FROM THE SUDETES 2003 REFRACTION DATA – ID 1756

*M. Novotny, Geophysical Institute CAS, Czech Republic*
*P. Hrubcova, Geophysical Institute CAS, Czech Republic*
*B. Ruzek, Geophysical Institute CAS, Czech Republic*
*A. Spicak, Geophysical Institute CAS, Czech Republic*

The international wide-angle refraction experiments POLONAISE 1997, CELEBRATION 2000, ALP 2002 and SUDETES 2003 carried out in central Europe in the last decade provided extensive seismic evidence of crustal und upper-mantle structure. The main source of uncertainties in interpretation of kinematic data is formed by the errors introduced during the phase correlation. Therefore the velocity determination based on the Pg and Pn first arrivals is considered to be more reliable in comparison with the depth determination using the more uncertain later-arrival reflection phases. Since the crustal structure determination is the first-order task in seismic interpretation, we tried to analyze this type of uncertainties. We compared results of alternative interpretations of reflection data from the SUDETES2003 profiles S01-S05 in the region of the Bohemian Massif. The study summarizes main results obtained in the following topics: Effect of space undersampling of correlated wide-angle reflections – what we can actually see on the regional sections with commonly used inter-station step about 3 km, in particular, at the critical distances due to MOHO reflection events. We also compared our results with available CDP time sections sampled in substantially smaller steps. Ambiguous MOHO reflections – in the region of the Bohemian Massif we do not observe a coherent MOHO reflection but a group of scaterred reflections coming from fragmentary reflectors in the crust-mantle transition zone. Apart from standard modelling approach giving smooth models with continuous structural boundaries we applied two other methods to the depth conversion of the most pronounced group of MOHO reflections. Comparing these alternative results we can evaluate the variance in structure determination arising from data uncertainties and method particularities.

### CRUST-UPPER MANTLE P-WAVE VELOCITY STRUCTURE IN YUNNAN, SOUTHWESTERN CHINA: GEODYNAMIC IMPLICATIONS – ID 1820

*Z. Bay, Institute of Geophysics, China*
*J. Badal, Universidad de Zaragoza, Spain*
*Z. Zhang, Institute of Geophysics, China*

We have investigated the detailed P-wave velocity structure of the crust and lithospheric mantle beneath Yunnan, Southwestern China, using travel time inversion involving finite-differences to constrain the structure above the crystalline basement, and the Raylnvr inversion technique to jointly invert P-wave velocities and reflector depths for two-dimensional models. The P-wave velocity models are further tested by synthetic seismograms and the best-fitting Bouguer gravity anomalies. The Moho depth changes from 56 km north of Yunnan to about 33 km in the southern part, and from 38-40 km west of Yunnan to 42 km in the eastern zone. Both the rapidly varying P-wave velocity in the deepest crust, which changes quickly to become 7.8 km/s in the topmost mantle, and the undulated Moho, show a complex crust/mantle transition with strongly contrasting velocity heterogeneities which reach typical velocities of 8.0 km/s at some sites. The extremely weak anisotropy of the upper-middle crust suggests that the surface deformation in eastern Tibet does not extend to the lower crust and is decoupled from the lower crustal flow. However, the apparent P-wave anisotropy of the lower crust and upper mantle underneath five cross points leads to a flow regime in north-south direction that not only agrees with contemporary tectonic deformation, but also provides an evidence for the rotation of the lower crust-upper mantle medium around the east Himalayan syntax. High velocity anomalies in the lower crust might be explained as intrusion of mantle material or remaining patches of ancient oceanic crust. The analysis of the combination of dry lower crust and wet mantle leads to reject the simple sandwich model for the continental lithosphere in the region.

## SC-E 0: Earthquake Prediction Research (Open Session – Posters Only)

Level 2

### PRECURSORY SWARM PRECEDING MAJOR SHOCKS IS A REAL SEISMIC PATTERN FOR LONG-RANGE EARTHQUAKE PREDICTION – ID 20

*D. Shanker, Indian Institute of technology Roorkee, India*
*H. N. Singh, Banaras Hindu University, India*
*V. P. Singh, Banaras Hindu University, India*

Precursory swarm/ anomalous seismic activity preceding large to great earthquakes with M $\geq$ 7 $\frac{1}{2}$ in northeast India have been identified using seismicity database from 1860 to 1985. It is observed that with the exception of three earthquakes (1908, 1912, and 1918), the large earthquakes of 1897, 1946, 1947, 1950 and 1951/9152 were preceded by well-developed epoch of swarm/ anomalous seismic activity in space and time well before their occurrence. Significant changes in the annual earthquake frequencies in the order of low-high-low ranging from 0-0.5, 01-33 and 0-0.7 events/ year during the epochs of normal/background, swarm/ anomalous and gap/ quiescence respectively have been observed prior to these mainshocks. The duration of precursory gap is observed to vary from 11 to 17 years for mainshocks of M 7 $\frac{1}{2}$ - 8.0, and from 23 to 27 years for M 8.7 and this period is dependent on the magnitude of the mainshocks. Well-defined patterns of anomalous seismicity are observed prior to 1964-1965, 12 August 1976 and 30 December 1984 (mb 5.6). All these mainshocks are preceded by seismicity patterns in the order of low- high- low similar to that observed prior to the mainshocks from 1897 to 1962. A prediction was made using the 1964 swarm that an earthquake of M 8 $\pm$ $\frac{1}{2}$ could occur any time from 1986 to 1990 in an area bound

by 21°- 25 $\frac{1}{2}$ °N latitudes and 93° - 96° E longitude within a focal depth of 100 ± 40 km based on Mp and Tp values in Arakan yoma fold belt. It is noteworthy that the 06 August 1988 earthquake with magnitude 7 $\frac{1}{2}$ and focal depth 115 km had occurred within the delineated zone. In addition, three consecutive swarm activities are identified in a limited area within the Eastern Syntaxis and these were not followed by any mainshock till date and could be potential zone for future earthquake.

## DYNAMIC PREDICTION OF SEISMIC HAZARD FOR THE CASPIAN-EASTERN TURKEY-IRAN REGION AND PIPELINE EARTHQUAKE IMPACTS – ID 126

*O. Babazade, Centre of Seismology and Earth's Physics, Azerbaijan*
*N. Babazade, Centre of Seismology and Earth's physics, Azerbaijan*
*L. Griesser, Consultant, Switzerland*

During global industrial development of oil and gas fields in any seismoactive region designing of the main oil and gas pipeline is particularly important for the assessment seismic hazards in these regions. This is one of the important tasks during antiseismic construction and for environmental protection. It is possible to prevent and minimize possible losses by means of normative maps of seismic zonation designated for the Caspian basin and for oil and gas pipeline routes. At present these maps significantly underestimate the region's hazard and current construction works are being performed without the proper assessment of this region's seismicity. It is possible to solve problems on assessment of seismicity on new conceptual base by methods of dynamic earthquake prediction. Such a long-time dynamic earthquake prediction for the Caspian-Eastern Turkey-Iran region was based on systemic seismogeodynamic approach to investigation of earthquake focal zones and on block model of seismokinematics of this region. The resulting map of dynamic regionalisation of the degree of seismic hazards up to year 2006 predicted not only place and strength of potential zones of the strongest earthquakes, but also the periods of increased probability of their occurrence within the source volume of the future mainshock. An early warning system of automatic telemetry have to be set up along with local and regional monitoring networks to predict short and medium term seismic hazard zonation the international earthquake monitoring and forecasting network.. Economically, continuous operation of large pipelines is extremely important because of the huge energy content of the oil flow. The earthquake detection system presented here consists of accelerometers, which measure the immediate effects of the earthquake, and pipeline deformation sensors, which detect secondary impacts to the pipeline.

## AN ATTEMPT TO EVALUATE THE SEISMICITY PHASE SPACE DIMENSION – ID 232

*L. Kortas, CMI, Poland*
*Z. Mortimer, AGH, Poland*

Studies of the seismic process generation are conducted on the base of nonlinear dynamics assuming that the process is multidimensional with an unknown number of dimensions. Determination of this dimension is important for an estimation of the prediction's possibility. From the time series of the epicenters/hypocenters, magnitudes and the time between two following events, the d dimensional embedded spaces are constructed and the correlation dimension D2(d) is evaluated. The value of d for which D2's stabilize ought to be considered as the phase space dimension. In most cases (in our calculations and in other published research works) these values are different for spaces reconstructed from different seismic variables. We have tried to incorporate all the available variables so that they all may simultaneously influence the D2. The analysis of the distances between subsequent events on the trajectories of the seismic flow allow for such a possibility. We have examined the sets of the events from naturally occurring and mining induced seismicity, for which the positive value of the Lapunov exponent pointed at deterministic chaotic behavior. The main problem was to choose the coefficients which normalize variables so as to construct satisfactory Mahalanobis distances.

## SCALING OF SEISMICITY AND DURATION OF THE FAILURE CYCLE – ID 321

*V. Smirnov, Institute of Physics of the Earth, Russian Federation*

The combination of two scaling laws - Gutenberg-Richter law and the fractal geometry of seismicity (known as unified scaling law too) - allows to estimate important physical parameter of the failure process: the duration of the failure cycle. The estimates of the duration of the lithosphere failure cycle are obtained and mapped from the instrumental data of the seismological catalogues for the last 40 years. A dependence of the duration on the size of failure area (on the earthquake source size) is estimated and mapped too. The estimates are obtained on two levels of detail: on global - for main seismic belts of the Earth and on regional - for selected regions. The values of failure cycle durations are within the interval from hundreds years to hundreds thousands years, average dispersion of this value from region to region is one and half - two orders generally. Found range of cycle duration is in agreement with known estimates of the earthquake recurrence interval derived from paleoseismological and geological data. The range of spatial variations in the failure cycle duration complies with current ideas on the possible regional variability in properties of the lithosphere and velocities of tectonic movements. In average for all regions in background mode the duration of the failure cycle depends weakly on the scale of failure (on the earthquake source size). On the contrary this relation is very bright for transient mode of seismicity, particularly for aftershock sequences. Considered physical parameters demonstrate the difference of seismic regime for two global tectonic structures - island arcs and oceanic rifts. This work was supported by the Russian Foundation for Basic Research, project no. 05-05-65122.

## NON-SEISMIC PRE-EARTHQUAKE SIGNALS: PHYSICAL REALITY – ID 427

*F. Freund, NASA ARC/SJSU, United States*

Earthquake hazards are assessed worldwide almost exclusively on the basis of probability models developed from seismic data. However, it has been known for a long time, in fact since antiquity, that before major seismic events the Earth often sends out non-seismic signals. These pre-earthquake signals are very varied. Those handed down from ancient times through oral and written tradition talk of strange animal behavior, of changes in water wells, of earthquake fog and earthquake lights. Modern technology has added more complex phenomena such as ionospheric perturbations, low-frequency electromagnetic emissions, and fluctuations of the infrared radiative flux from the land surface. All these pre-earthquake signals have gotten "a bad name" in the science community. The reason is that, until now, nobody had been able to offer a physically consistent explanation how Earth might be able to produce such varied signals. Many hypotheses have been proposed but all seem to be flawed. I'll describe innovative rock deformation experiments, which demonstrate that, when igneous rocks are stressed, they generate electric currents – like a battery. The currents propagate through the rocks. They fluctuate. They cause the rock surface to become positively charged and to shine in the infrared. Key is the discovery of electronic charge carriers that normally lie dormant in the rocks but are awakened by stress. These charge carriers have been overlooked in spite of decades of intense studies of the electric properties of rocks. They are defect electrons in the oxygen sublattice, known as "positive holes" or p-holes for short. The p-holes are long-distance runners. They live and travel in the valence band. They jump from grain to grain. They can cross boundaries between different types of rocks. They hold the key to understand the diverse pre-earthquake signals. They hold the key to resolve past controversies in an amicable way.

## THE BATTERY EFFECT: SQUEEZING ELECTRIC CURRENTS OUT OF ROCKS – ID 428

*F. Freund, NASA ARC/SJSU, United States*
*A. Takeuchi, Niigata University: Chemistry, Japan*

*B. W. S. Lau, SETI Institute, United States*

The ultimate goal of earthquake prediction is to predict place, time and magnitude of an earthquake within narrow limits. This goal may never be achieved to the satisfaction of some, but we should be able to do better in the future than today. An important step would be to move away from the nearly exclusive use of seismology to construct predictive probability models. We have to take into account non-seismic signals that the Earth reportedly sends out in a bewildering variety before major events. When we squeeze one end of a 1.2 m long slab of an igneous rocks such granite, we observe two electric currents flowing out of the stressed rock volume. One (carried by electrons) flows directly to ground. The other (carried by defect electrons) flows through the unstressed portion of the rock, out the far end, and to ground. The two currents are of equal magnitude but of opposite sign. They are tightly coupled and tend to fluctuate. The defect electrons that can flow through unstressed rock are charge carriers in the oxygen anion sublattice, also known as positive holes or p-holes for short. Extrapolating our laboratory data to geophysically relevant dimensions suggests that each cubic kilometer of stressed rock can generate currents on the order of 1000-100,000 amps flowing for days or even weeks and months. We have a fairly good understanding of the nature of these currents, what the dormant precursors are that exist in the rocks and become activated by stress. Importantly, the currents are not piezoelectric nor are they caused by any other process discussed in the literature so far. Such stress-activated currents in Earth's crust hold the key to decipher a wide range of electric, magnetic and electromagnetic signals that have long been reported in connection with impending earthquake activity.

## ACOUSTIC REGIME RESPONSE TO HARMONIC LOAD IN LABORATORY EXPERIMENT – ID 586

*S. Stroganova, Schmidt Institute of Physics of the Earth, (RAS), Russian Federation*
*A. Ponomarev, Schmidt Institute of Physics of the Earth, (RAS), Russian Federation*
*V. Smirnov, Schmidt Institute of Physics of the Earth, (RAS), Russian Federation*

Features of acoustic emission (AE) in sample of Westerly granite under confining pressure of 160 MPa were studied. The pre-fractured core was deformed by a uniaxial stress up to stick-slip events. The experiments were carried under constant strain rate of 10-7 l/s. The axial load was modulated by sinusoidal vibration of 200 s periods and a few percents of amplitude peak-to peak relative to main stress. This vibration action generates the synchronous variations of AE. It was found that the most clear response to load oscillations was appeared during periods of acoustic "aftershock" sequences whereas the acoustic answer over stationary AE period was much more weak (up to disappearance). The main conclusion could be done from these tests – the synchronization of load and AE rhythms arises in the course of transient acoustic regime when the media passes in non-stable state and has a high strain-sensitivity. The experiments were conducted in cooperation with Dr. S.Stanchits (GFZ, Potsdam) in the laboratory of rock mechanics headed by Prof. D.Lockner (USGS, Menlo Park). The work was supported by RFBR grant 05-05-08022.

## MONITORING OF TIDAL COMPONENT OF SEISMIC NOISE FOR EQ PREDICTION IN KAMCHATKA: NEW ASPECTS – ID 728

*Y. Kugaenko, Kamchatkan Branch, Geophysical Survey, RAS, Russian Federation*
*V. Saltykov, Kamchatkan Branch, Geophysical Survey, RAS, Russian Federation*

The strategy of identification of large earthquake precursors in tidal component of high-frequency seismic noise (HFSN) is developed in Kamchatka from 1988. HFSN is the seismic oscillations in frequency range of the first tens of Hz. Signal envelope is recorded and analyzed. The main investigated effects are modulation of HFSN by the Earth tides and temporal variations of the HFSN parameters connected with the large earthquakes preparation. Before local large earthquakes synchronization of HFSN tidal component with tidal wave of gravitational potential was found. By 1992-1996 data this effect had been obtained from some weeks to 2 months before earthquakes with magnitude M>6.0 and epicentral distance D<250 km. So the stabilized phase shift of the HFSN O1-component before strong earthquakes has fixed values. In given report we present examples shown the connection of HFSN tidal variations with 22 strong Kamchatkan earthquakes since 1992 to 2005. New empirical M-D dependence for predicting earthquakes is shown. In 2003-2004 in Kamchatka two deep earthquakes with magnitude near 7 occurred: 16-Jun-2003, Mw=6.9; 10-Jun-2004 Mw=6.8. These earthquakes were not only at a short distance, but they have the same source parameters and waveforms. We can consider them as doublet. In this case we can wait the similar behavior of earthquake precursors. It is shown that the HFSN anomalies before these earthquakes have similar duration and similar value of phase parameter. Moreover such coincidence was obtained by data of 2 HFSN stations. It is concluded that the anomalous value of tidal parameter is linked with location and parameters of future earthquake. Hypothesis of connection between phase stabilization level and source was confirmed. New methodical aspects are directed to decreasing of uncertainty in spatial location during earthquake prediction. This research is supported by RFBR Grant 04-05-65210a.

## RESULTS OBTAINED THROUGH THE ELECTROMAGNETIC METHOD FOR SHORT-TERM PREDICTION OF VRANCEA (ROMANIA) EARTHQUAKES – ID 839

*I. A. Moldovan, National Institute for Earth Physics, Romania*
*D. Enescu, National Institute for Earth Physics, Romania*
*B. D. Enescu, Research Center for Earthquake Prediction, Kyoto, Japan*

The paper is based on geomagnetic records made at Muntele Rosu Observatory (Romania), during the time interval from December 1997 to November 2005. The results of the data processing are illustrated in diagrams of the magnetic impedance Bz(t)/Bx(t), where Bz is the vertical component of the geomagnetic flux density and Bx its horizontal component. The theoretical reasons for using ratios Bz(t)/Bx(t) and Bz(t)/By(t) of the geomagnetic flux density components as earthquake prediction tools are first of all provided. Since the roughly EW-oriented By component was negligibly small, we found that using , the time variation of the mean daily ratio Bz(t)/Bx(t), was both right and advisable. The time variation of Bz(t)/Bx(t) is closely examined in correlation with Vrancea seismic activity. This correlation prove that out 134 earthquakes of magnitudes M>Mo (Mo=3.6-4.0, usually Mo=3.9, in the case of subcrustal earthquakes, while in crustal earthquakes Mo=2.8-3.0), 114 (or 85%) were preceded by significant perturbations of the magnetic impedance Bz/Bx. The precursor merit of the $\zeta(t)$ ratio has been significantly improved by determining a relation between the precursor time tp and the magnitude of the earthquake. The precursor time tp is defined as the time interval between the beginning of the precursor magnetic perturbations and the beginning of the predicted earthquake.

## GEO-ASTROPHYSICAL ANALYSIS ON SIGNIFICANT GREECE EQS 1900-2005: IMPLICATIONS FOR EQ PREDICTION – ID 950

*N. Venkatanathan, University of Madras, India*
*N. Rajeshwara Rao, University of Madras, India*

Seismicity of Greece is concentrated in east-trending and northeast-trending zones of deformation. The east-trending zones are most prominent in mainland Greece, are characterized by predominantly normal faulting, and have produced earthquakes with magnitudes of about 7. The northeast-trending belts are characterized by predominately strike-slip fault earthquakes. A northeast-trending zone of predominantly strike-slip earthquakes

occurs off the west coasts of Cephalonia and Lefkada, western Greece, and other northeast-trending zones occur beneath the Aegean Sea east of the Greek mainland. Though there have been several attempts at earthquake prediction from different perspectives, this attempt aims at establishing the role planetary configurations and their forces as a definitive means of earthquake prediction. When two or more than two planets, Sun and Moon are aligned more or less in line (0 or 180 deg) with the Earth, then the Earth would be caught in the middle of a huge gravity struggle between the Sun and the planets. The gravitational stresses would change the speed of the Earth in its orbit. When the speed of rotation of the earth changes the tectonic plate motion also gets affected. So the planetary forces in the opposite direction to the rotation of earth act as a triggering mechanism for the accumulated stress at faults and plate boundaries to be released abruptly. This does not, however, mean that earthquakes will occur at all edges of the plate boundaries. Two of the parameters contributing to the triggering of an earthquake at a place are - a) distance of epicenter from the planet position and b) direction of force acting at the possible epicenter. From the analysis of "significant Greece earthquakes" for past 105 years, the relationship between (i) Latitude, Longitude, and Magnitude of the tremor and (ii) distance from the planet and direction of forces acting can be inferred.

## NEW APPROACH TO THE DETAILED QUANTITATIVE ASSESSMENT OF THE SEISMIC HAZARD – ID 1551

*E. Rogozhin, Institute of Physics of the Earth RAS, Russian Federation*
*G. Reisner, Institute of Physics of the Earth RAS, Russian Federation*
*L. Ioganson, Institute of Physics of the Earth RAS, Russian Federation*

The new techniques for detailed quantitative assessment of the seismic hazard are developed at the Institute of the Physics of the Earth RAS including the extraregional seismotectonic method, trenching and special deciphering of remote data. Using the extraregional seismotectonic method the first estimates of maximal magnitudes for different regions of East European platform and adjacent seismic active areas are obtained. These estimates are directing hints for conducting the paleoseismogeological investigation by trenching which enables the receiving data on the occurrence period for strongest earthquakes. The special deciphering of remote data provides information on the recent active geological structures. Combination of these three methods enables the recognising the potential seismic sources of strong earthquakes.

## EARTHQUAKE PREDICTION - NEW STRATEGY – ID 1552

*O. Kondratiev, Institute of Physics of the Earth RAS, Russian Federation*

Any indirect precursor depends not only on the strain-stress change level of medium but also on the host of the other factors which often may be of more significance. Both the precursor set and character of their manifestation can be diverse not only in each seismic active region but also in each observation place. The separate or integrated precursors with large or small «distance of affecting» do not allow the solution of the operative prediction in term of evaluation of the place, time and energy of earthquake. Thus, the specific own approach of local application for the earthquake prediction should be developed for different regions. The concept of the active objective-oriented search of the potential source zones and receiving the direct information on the medium parameter changes in these zones in the process of the preparing and development of the earthquakes (the source monitoring) is being proposed.

## PROBABILITY OF RADON PRECURSORS OF EARTHQUAKES (M<5.0) IN THE TERRITORY OF ARMENIA – ID 1626

*H. Hovhannisyan, Institute of Nuclear Physics PAS, Poland*

The study was performed at the Armenian National Survey for Seismic Protection (NSSP).

For assessment of the probability of seismic realization of radon (Rn222) anomalies-precursors in the territory of Armenia the study of eight seismic events (which have occurred from 1990 till 2005 in the territory of Armenia) were carried out. The studies have been conducted basing on the data recorded in 23 stations of underground radon measuring network of Armenian National Survey for Seismic Protection (NSSP). While analyzing them and identifying the possible seismogenic anomalies the atmospheric temperature, atmospheric pressure and the annual process of radon exhalation have been taken into consideration. The method of analysis applied to the radon and earthquake data consisted of retrospective identifying radon anomalies and resulted in 58 precursory anomalies. Typology of anomalies was carried out and the parameters of anomalies-precursors were determined. Also the parameters and the characteristics of those seismogenic anomalies had been identified. On the basis of the Earthquake Testing Methodology (worked out by H.Petrosyan) the /P/ probability of seismic realization of radon precursors has been determined. The main results are as follows: 1. All the anomalies are short-term and clearly expressed. Operative anomaly (P=0.1) has been recorded only once in one station. The duration of the anomalies ranged from 1 to 207 days. The lowest probability of seismogenic anomalies is P=0.1 and the highest one is P=1.0. 2. Mean value of (P) probability of seismic realization of short-term radon precursors is 45% in case of earthquakes (M<5.0) which took place in the territory of Armenia.

## THE ESTIMATION OF THE PHASE SPACE DIMENSION FOR GEOPHYSICAL TIME-SERIES – ID 1699

*A. Cherepantsev, Taganrog State University of Radioengineering, Russian Federation*
*V. Smirnov, Physics Dept., Lomonosov Moscow State University, Russian Federation*
*J. Qian, Institute of Earthquake Science, CEA, China*

The attention to developing of nonlinear dynamics approaches in the analysis of the complex geophysical fields in many respects bases on clear physical sense of estimated dynamic parameters. Their values allow to estimate model regularities in phenomena behaviour. The phase space dimension of a dynamic system is one of such parameters. The possibility of its estimation on single temporal realization was studied. Time series of the long term observations of apparent electrical resistivity and the relative vertical displacement of a surface are chosen as components. Data ware obtained in the Institute of Earthquake Science, China Earthquake Administration. Found embedding dimension m=7-8 for variations of apparent electrical resistivity and m=6 for variations of the relative vertical displacement can characterize complexity of the dynamic system model of the given fields. Proposed technique was used also for the analysis of correlation degree between various dynamic systems and its parameters. In this case the correlation is understood as number of the independent parameters simultaneously taking part in forming of the dynamic behaviour of various physical fields. The calculations specify, that variations of apparent electrical resistivity in perpendicular directions are produced by a common system of the dynamic equations while dynamic systems, defining apparent electrical resistivity and the relative vertical displacement of a surface are correlated only in part. As the value of embedding dimension of a system «apparent electrical resistivity - relative vertical displacement of a surface» is m=12, the number of common influencing parameters is n=2. Presented methods and results can be used in development of complex modeling of the geophysical processes and in new approaches and methods of creation of the prognostic characteristics for physical fields behaviour.

### A MULTIDISCIPLINARY METHOD ON PRECURSORY PHENOMENA ASSOCIATED WITH STRONG VRANCEA EARTHQUAKES – ID 1714

*A. S. Moldovan, AZEL Designing Group, Romania*
*I. A. Moldovan, National Institute for Earth Physics, Romania*
*C. Panaiotu, Faculty of Physics, Romania*
*A. O. Placinta, National Institute for Earth Physics, Romania*

The proposed paper reffers to accomplishing a multidisciplinary research system on precursory phenomena associated with strong intermediate Vrancea earthquakes, by involving associative research methods which to gather representants of related domains to a united scientifical effort of identifying, diagnosing and characterising the specifical mechanisms of these phenomena's occuring and manifesting. The paper's main goal is to research the interaction mechanisms within the macrosystem consisted by the three coupled systems - The Planet - The Atmosphere - The Space and which are related to phenomena that might be charaterized as precursors of strong earthquakes, the causality and the mode in which the three systems are related, by the meaning of information disseminated by a complex infrastructure made of monitoring units for specific parameters. It is proposed to develop a multidisciplinary research system in the field of earth's physics, atmosphere's physics and space's physics, which to allow the studying of the possible correlations between the observed phenomena (infrsonic and VLF electromagnetic emmissions and geomagnetic anomalies) at each of the three-layer stages, by analysing the mode in which they are causal related. The infrastructure will be deployed in Vrancea seismogenic area and out of it, as well.

### RADON MONITORING IN FLUIDS IN SEISMIC AREAS – ID 1829

*A. Riggio, OGS, Italy*
*M. Santulin, OGS, Italy*
*J. Vaupotic, Josef Stefan Institute, Slovenia*
*F. Italiano, INGV, Italy*
*H. Friedmann, Institut fur Isotopenforschung und Kernphysik, Austria*

The border area among Italy, Slovenia and Austria had been hit by strong earthquakes in the past (1348 Villach, 1511 Slovenia-Italy), and recently in 1976 (Friuli) and 1998 (Bovec). The tectonic structures crossing the study area are uninterrupted and in Friuli there is a crossing between the Alpine and Dinaric chains. A long-term geochemical monitoring was carried out in this area, and it consists in: an Austrian station at Warmbad Villach, where the radon concentration in a thermal spring is measured by an ionisation chamber; three stations located in Slovenia, at Bled and Hotavlje, designed to monitor radon concentration, water temperature and electrical conductivity in thermal water by a Barasol MC 450 probe; a station located in Friuli (Italy) equipped with a continuous radon recording Lucas scintillation cell (Prassi of Silena) installed in a 40.5 metres deep well, united to a meteorological station measuring atmospheric pressure, rainfall, air temperature, water temperature and groundwater level, and with a Barasol probe located 50 meters apart from the well. The data recorded in the same site with both radon instruments have been compare as the data recorded in two different kinds of site (water thermal and soil gas). The connection between the anomalies of chemical and physical parameters and seismic events has been explained by the dilatancy model. Radon concentration in water and in soil gas, concentrations of anions and cations in water and meteorological parameters have been analysed for short and long-period anomalies. For example, geochemical data evaluated with seismological data coming from the Friuli seismometric network since 1977, allowed us to relate the behaviour of the b parameter of the Gutenberg and Richter law (1944) with the long period radon concentration variations related to the geodynamic process.

### HYDROLOGIC PRECURSORS OF WEAK EARTHQUAKES IN THE BOHEMIAN MASSIF IN 2005 – ID 1852

*M. Broz, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*L. Kasparek, T. G. Masaryk Water Research Institute, Czech Republic*
*J. Malek, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*V. Stejskal, Institute of Rock Structure and Mechanics AS CR, Czech Republic*

The Hronov-Porici fault zone (HPFZ) is one of the most seismoactive areas in the Bohemian Massif. HPFZ is situated on the NE margin of the variscan Bohemian Massif. Its complicated and long-lasting evolution begun in the Late Paleozoic. During the last 300 years three earthquakes with magnitude M > 4 occurred in the area of HPFZ. Since 2005 the area is monitored with a small-aperture array composed of four seismic stations. Moreover, fluctuations of groundwater level are observed in five hydrogeologic boreholes (depth 35 – 305 m), to study possible relations between seismic activity and groundwater regime. In 2005 two earthquakes occurred – in August 2005 (M = 2.4) and October 2005 (M = 3.3). Both earthquakes were preceded by an abrupt increase of groundwater level in the deepest one of the five observing boreholes. These anomalies were recorded 13 hours before the August 2005 event and 31 hours before the October 2005 event.

### MULTIFRACTAL SCALING OF THERMALLY ACTIVATED RUPTURE PROCESSES – ID 2065

*G. Ouillon, LPMC, France*
*D. Sornette, ETH, Switzerland*

We propose a multifractal stress activation model combining thermally activated rupture and long memory stress relaxation, which predicts that seismic decay rates after mainshocks follow the Omori law with exponent p linearly increasing with the magnitude M of the mainshock. We carefully test this prediction on earthquake sequences in the Southern California earthquake catalog: we find power law relaxations of seismic sequences triggered by mainshocks with exponents p increasing with the mainshock magnitude by approximately 0.1–0.15 for each magnitude unit increase, from p(M=3) 0.6 to p(M=7) 1.1, in good agreement with the prediction of the multifractal model. We also propose a numerical implementation of the model, considering stochastic rupture sequences on a discrete network of faults subjected to antiplane loading stress. Each fault nucleates thermally activated seismic events which can propagate in the system. We study the spatial localization of strain, the distribution of size of events, as well as aftershock sequences and their dependence on the main inputs of the model: temperature, strain rate and disorder.

## SC-E 1: Earthquake Forecasting and Society

Level 2

### THE SEISMO - SYNOPTIC METHOD OF SHORT-TERM FORECASTING OF EARTHQUAKES : THE SCIENTIFIC BREAKTHROUGH – ID 557

*V. Bokov, RSHU, Russian Federation*

The five years' experience of operative short-term forecasting of surface earthquakes on the territory of Northern Hemisphere has shown that the forecast of earthquakes with a forecast-time interval for 2 days is a real implementation of one of main scientific problems of mankind. This outcome was reached due to seismo - synoptic method. The method grounded on interplay of spatial dynamics of atmospheric weights with exogenetic processes of earth crust, and also with endogenic processes of the upper mantle and registration of solar activity. At the same time in Russia for several years exists a website http://quake_vnb.rshu.ru, on which in an operative mode the skilled short-term forecasts of earthquakes with the justifience about 75 % are exposed. The

given forecasts are developed on a basis of a seismo-synoptic method. The variability of atmospheric circulation influences the occurrence of the basic harbingers of earthquakes (allocation of lithosphere gases, a change of spatial intensity of radon, changes of a level of earth waters, acoustic noise etc.). The basic harbingers appearing at lengthways of a tectonic break testify to accumulation of superfluous pressure in terrestrial crust and about prospective strong earthquake, which frequently does not occur. At the same time the analysis of synoptic conditions points out precisely on occurrence of the specified harbingers, and also allows defining a place, time and force of earthquake. The statistical estimations of justifience of short-term earthquakes for 4,5 years are presented in the report. 3573 earthquakes with magnitude from 4 up to 7 were predicted during this time, from which 2679 were justified. The forecasts of last destructive earthquakes Iran 2002, Algeria 2003, Morocco 2003, Japan 2004, 26 of December 2004 and 28 of March 2005 at Sumatra, 8 of October 2005 Pakistan. The accuracy and the justifience of short forecasts of earthquakes can be increased up to 90-95% only in cooperation of the meteorologists, geophysics and seismologists.

### NEXT GREAT EARTHQUAKE IN TEHRAN-IRAN – ID 579

*M. Ashtari Jafari, Tehran University, Iran (Islamic Republic Of)*
*M. R. Hatami, Tehran University, Iran (Islamic Republic Of)*

Seismic activity changes in time and space. It is possible to employ statistical methods to model seismicity and to predict its future variations. Several stochastic earthquake generating models have been employed for this purpose. After removing aftershocks small earthquakes show Poissonian distribution while great and medium shocks are considered to be temporarily clustered (non-Poissonian) in a given zone. A Poissonian model may provide earthquake occurrence probability of any size up to the characteristic earthquake of the area which is independent of the size and the elapsed time since the last great event. Considering temporal clustering one can estimate the probability of happening of a future event in the given time interval especially if there exist knowledge of previous events. Tehran the capital of Iran is located within an active seismic zone including several active faults. The city and its surrounding are highly populated while gossips about occurrence of a great earthquake make people to go out of their homes from time to time. Then it seems reasonable to forecast the time to the next great earthquake around this city by statistical techniques. So in this paper the elapsed times since last large earthquakes around this city is related to the conditional probability of happening of the next great earthquake employing different distributions like Weibull, Rayliegh and Pareto. The uncertainty in the parameters of the mentioned distributions is calculated also.

### SOME RESULTS OF SEISMICITY TEMPORAL VARIATION FOR SEISMIC HAZARD ASSESSMENT IN GREECE – ID 1097

*G. Papadopoulos, Earthquake Planning and Protection Organization, Greece*
*I. Baskoutas, Geodynamic Institute National Observatory, Greece*

Recently an effort, for the regular monitoring of the spatio temporal variation of the seismicity in Greek territory, has been made, by means of the FastBEE software tools. FastBEE software was developed in order to elaborate seismic data (earthquake catalogues), among other facilities draw the time series of some seismicity parameters, in selected areas at once, with the aim to asses earthquake hazards. By the application of the previously mentioned tools the temporal variation analysis of the seismicity, expressed in terms of the logarithm of number of earthquakes, energy released, logE2/3, b-value and mean depth, has been examined for the period 1990 to January 2006. In this approach the qualitative character of the temporal variation of b-value was found to be independent on the applied method. Moreover it is found also that the minimum representative magnitude doesn't affect relative b-value temporal estimates. Results, especially b-value temporal estimates, show remarkable anomalies before the recent October 2005 to January 2006, strong earthquakes occurrence, with magnitude greater than 6.0Richter, in Greek territory. Moreover, in the frame of this investigation, significant anomalies have been observed, three more areas. These areas are located in the West part of central Aegean Sea (Sporades Islands), in the Southern East part of the Hellenic arc (Dodecanese Island) and in the east part of Crete Island respectively. These anomalies can be interpreted, with high probability, as a premonitory stage of some strong earthquakes, with magnitude greater than 6.0 Richter within 2006. Relative comparisons of the temporal variation of examined parameter show that there is no relation between parameter logN with respect b-value and energy released, in the examined areas. On the other hand, as it was expected, there is strong correlation (R>0.8) of b value respect to the parameter logE2/3.

## SC-E 2: Deterministic and Probabilistic Prediction Methods: Theory, Applications and Case Studies

Level 2

### PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR THREE SITES IN THE UNITED ARAB EMIRATES – ID 128

*G. Aldama, Imperial College, UK*
*J. Bommer, Imperial College, UK*
*C. Fenton, Imperial College, UK*

Construction projects in the United Arab Emirates (UAE) are currently faced with conflicting information regarding seismic design requirements. Historic seismicity in the UAE is relatively low, and both a published hazard for the Arabian Peninsula and UBC 1997 indicate seismic hazard sufficiently low as to ignore earthquake-resistant design considerations for normal structures. Nonetheless, local authorities in the UAE require the use of higher seismic design loads for tall structures. The only supporting evidence for this is the Global Seismic Hazard Assessment Project (GSHAP) map and a recent paper published by researchers in the UAE. The former was mapped by simulating the attenuation effect of the seismicity in Iran, and the latter uses a seismic source zonation that is incompatible with the regional seismotectonic tectonic framework. As a result, both maps severely overestimate the seismic hazard.

We present a new probabilistic seismic hazard analysis for three sites in the UAE (the cities of Abu Dhabi, Dubai and Ra's al Khaymah) and Uniform Hazard Spectra at different return periods. This hazard assessment uses a detailed source characterisation model incorporating the latest seismotectonic data for the region. A full treatment of uncertainty is made through logic trees to incorporate uncertainties both in the source characterisation and, in particular, the selection of appropriate attenuation equations for this region without local strong-motion data. The hazard curves for the three sites are presented showing the full range of uncertainty. Using both the mean and median hazard curves, the peak ground and spectral accelerations at return periods generally considered for design are found to be significantly lower than those from previous studies. This confirms that, for standard construction, seismic design considerations are probably not required. However, the long period effects of distant, large earthquakes in the Zagros and Makran regions could be significant for very tall structures.

### ISTANBUL EARTHQUAKE HAZARD MAP – ID 509

*I. Sanri, Bogazici University, Turkey*
*S. Karapinar, Bogazici University, Turkey*

The main purpose of this study is to obtain the seismotectonic characteristics of Istanbul based on earthquake risk and vulnerabilities of existing structures against a potential earthquake in the region. The distribution of structural damage due to

probable earthquakes of different magnitudes and return periods is computed. Risk maps are produced for 30 districts of Istanbul showing the geographical extend of earthquake hazard.

The basic idea underlying this investigation is the estimation of expected earthquake magnitudes in the future from past earthquakes in the region. Therefore, the goal of the first part of the study is to estimate the expected earthquake magnitude in Istanbul with a prescribed return period. Historical earthquake data between 1905 and 2004 is used to evaluate the seismic activity in the area. Using the Gumbel-Gutenberg-Richter approaches, the earthquake risk for different districts of Istanbul is calculated. Four different earthquake scenarios are developed with four different return periods. These are 25, 50, 75 and 100 years. Using these scenarios, the maximum magnitude of a probable earthquake to occur in Istanbul is estimated within a prescribed period.

In the second part, the damage states of a total of 538,977 reinforced concrete structures located in the region are investigated using the above mentioned earthquake scenarios. The damages due to potential earthquakes on these structures are classified and the distribution of the damage is estimated. In the conclusion, risk maps of probable earthquake damage for the expected occupancy of life duration are produced.

## A MULTIDISCIPLINARY METHOD ON PRECURSORY PHENOMENA ASSOCIATED WITH STRONG INTERMEDIATE VRANCEA EARTHQUAKES – ID 875

*A. S. Moldovan, AZEL Designing Group, Romania*
*I. A. Moldovan, National Institute for Earth Physics, Romania*
*C. Panaiotu, Faculty of Physics, Romania*

The proposed paper reffers to accomplishing a multidisciplinary research system on precursory phenomena associated with strong intermediate Vrancea earthquakes, by involving associative research methods which to gather representants of related domains to a united scientifical effort of identifying, diagnosing and characterising the specifical mechanisms of these phenomena's occuring and manifesting. The paper's main goal is to research the interaction mechanisms within the macrosystem consisted by the three coupled systems - The Planet - The Atmosphere - The Space and which are related to phenomena that might be charaterized as precursors of strong earthquakes, the causality and the mode in which the three systems are related, by the meaning of information disseminated by a complex infrastructure made of monitoring units for specific parameters. It is proposed to develop a multidisciplinary research system in the field of earth's physics, atmosphere's physics and space's physics, which to allow the studying of the possible correlations between the observed phenomena (infrsonic and VLF electromagnetic emmissions and geomagnetic anomalies) at each of the three-layer stages, by analysing the mode in which they are causal related. The infrastructure will be deployed in Vrancea seismogenic area and out of it, as well.

## UNCERTAINTIES IN A DETERMINISTIC AND PROBABILISTIC APPROACH ON LIQUEFACTION SUSCEPTIBILITY – ID 1011

*J. Buchheister, Institute for Geotechnical Engineering, Switzerland*
*Y. Y. Bayraktarli, Institute of Structural Engineering, Switzerland*
*J. Dr. Laue, Institute for Geotechnical Engineering, Switzerland*
*M. Faber, Institute of Structural Engineering, Switzerland*

Evaluation of liquefaction susceptibility is affected by different sources of uncertainties. These uncertainties may be due to the applied models as well as the limited availability of data from soundings and differences in quality. In the context of this paper some of the uncertainties will be discussed based on both, a deterministic and a probabilistic approach using two state-of-the-art methods for evaluation of liquefaction susceptibility in combination and stand alone. First, deterministic procedures using the modified chinese criteria and the simplified procedure are discussed based on their sensitivity to input parameter, which might vary at the borderline.Second, the sensitivity of the input parameter is studied in a probabilistic analysis, while uncertainties of the soil parameters have been incorporated into a Bayesian Probabilistic Network. Third, the results of the deterministic analysis are compared with the probabilistic analysis based on available data from the city of Adapazari in Turkey where damages caused by liquefaction were numerous. Conclusions for further activities in this field will be drawn.

## STRUCTURAL MODEL FOR SEISMIC HAZARD ANALYSES OF TBILISI, REPUBLIC OF GEORGIA – ID 1452

*T. Godoladze, United National Survey for Seismic Protection, Georgia*
*L. Hutchings, Lawrence Livermore National Laboratory, United States*

The Caucasus is the one of the most active segments of Alpian-Himalaian collision belt. Based upon macroseismic effects historical earthquakes occurred within Tbilisi city in 1682, 1803, 1804, 1819. On 25 April of 2005 Tbilisi was hit by magnitude Ms=4.5 earthquakes. Tbilisi city has a population of about 1.3 M(about one fourth of population of whole country), and engineering structures are generally poorly designed. Over 8 people died and 100 buildings collapsed as a result of the 2002 earthquake. Our main concern is what will be the effects of future possibly large earthquakes. Due to political and economic reasons, no modern integrated analyses of tectonic and seismicity has been conducted for the vicinity of Tbilisi city. We evaluate previous earthquake catalogue to identify a cohesive dataset of travel time picks, perform a one-dimensional velocity inversion to obtain an average model of Georgia, use moment tensor inversion to refine the model near Tbilisi, and relocate local seismicity. We then incorporate these results with recent geological and literature studies of the tectonics to develop a tectonic model for the vicinity of Tbilisi. We used physically based strong ground motion prediction methodology to predict the range of ground-motion hazard for earthquakes, along specific faults or within specific source volumes and to incorporate this into probabilistic seismic hazard analyses(PSHA).

## SEISMIC RISK ASSESSMENT OF THE TERRITORY OF VLADIKAVKAZ CITY – ID 1462

*N. Nevskaya, Geophysical Center of Experimental Diagnostics, Russian Federation*
*V. Zaalishvili, Geophysical Center of Experimental Diagnostics, Russian Federation*

For seismic risk assessment based on the investigation of geophysical and geological conditions including seismological and ground conditions of the territory of the North Ossetia-Alania there were formed database of seismic effect, catalogue of earthquakes and active faults of the Caucasus, etc. Based on the received data there was performed assessment of seismic risk caused by different seismic sources. Model of seismic energy attenuation was selected. First time for the Russian territory for such problem solution there was used value of acceleration along with the traditional value of earthquake occurrence that is intensity. Thus we received calculated value of seismic effect on the investigated territory (Vladikavkaz city). First time in Russia probability maps was made in GIS technology. Later there was performed seismic microzonation of the territory. In connection with work realization for the first time in the North Caucasus in the urban area there was formed local network of seismic observations consisting of 4 modern seismic stations "Delta-Geon". Stations were installed in sites with different soil conditions typical for the territory of Vladikavkaz city. There are many seismic records received since August 2004. In particular there was recorded earthquake happened 7 January 2005 with the epicenter in Chechnya and occurred on the territory of Vladikavkaz city with the intensity of 4. Next important part of the work was inspection of buildings, estimation of vulnerability and seismic risk estimation based on seismic conditions. In this work all the recent achievements of the modern seismology, engineering seismology and earthquake-resistant constructional engineering were used and it was undoubtedly useful and interesting.

### SOME ASPECTS OF STRONG EARTHQUAKES SOURCE AREAS SEISMIC MONITORING – ID 1919

*A. Lutikov, Geophysical Survey of RAS, Russian Federation*

Physically justified choice of seismological parameters for seismic situation monitoring directed to strong earthquakes precursors finding is based on the supposition, that the stress upbuilding process during the strong earthquake preparation leads to simultaneous changes in seism tectonic deformation process. In this way the seism tectonic deformation concept introduction is very important. From the expression of seism tectonic deformation it is possible to derive two independent parameters for seismic situation monitoring: summarized scalar seismic moment per the sampling interval or cumulative scalar seismic moment, that can be considered as the Benioff's graph analog, and so called order coefficient or ordering index k ($0<k<1$). It is possible to introduce ordering index k as the ratio of the matrix norm of average by the sampling interval seismic moment tensor (CMT) to the average by this sampling interval CMT matrix norm. To avoid overwhelming influence of stronger events before averaging the CMT matrixes are normalized to the scalar moment. It was established that the best sampling interval for interpretation is 3 years. Ordering Index was used with the aim of retrospective seismic situation analysis in the source areas of 7 strongest earthquakes for the last decade in different regions of the World. Almost in all the cases one can observe the minima values of k for 2-3 years before strong EQ and it's increasing up to maximum in the moment of EQ and in the beginning of aftershock process. It was found, that such changes of k is connected to process of steep modification of background seismicity in strong EQ source area. The character of such modification is connected to lining CMT eigenvectors of background events practically in parallel to CMT eigenvectors of the main event on the eve, in time and at once after its occurrence.

## SC-E 3 & SC-F 2: Time-Dependant Earthquake Hazard Assessment

Level 2

### SEISMIC HAZARD PREDICTION IN SOME PROVINCES OF IRAN USING FUZZY LOGIC – ID 59

*A. Noorzad, Tehran University, Iran (Islamic Republic Of)*
*A. Noorzad, Power and Water University of Technology, Tehran, Iran (Islamic Republic Of)*
*N. Zamani, Tehran University, Iran (Islamic Republic Of)*

The estimation of seismic hazard level has significant influence on the design of different structural and non-structural elements. Although the basic methodologies used in seismic hazard analysis are well established, but the complex process of earthquake occurrence in a region and uncertainty in hazard modeling which is based on probabilistic method has the following problems:

- Earthquake event prediction doesn't follow Poisson process in all regions.
- With respect to the law of earthquake occurrence as Richter-Gutenberg relationship, it is impossible to achieve the solution by maximum likelihood estimation method.

To overcome the above shortcomings, it is proposed to simulate the uncertainty of hazard by fuzzy mathematics. Based on the past earthquakes of a region, the events are modeled as non-stationary time-series in order to forecast all features using fuzzy relationship.

Having a reliable assessment, the region should meet the homogeneous seismic condition. However, there is less attention to control this test in conventional method. In the present research, the information of seismic events in Iran consisting of the source and seismotectonic condition is carried out by Gath and Geva clustering algorithm using fuzzy logic. Each cluster is assigned to seismic province illustrating homogeneous seismic situation in accordance to identical seismotectonic condition.

Utilizing historical seismic information and data set, clustering has been accomplished by fuzzy C-mean and replacing the prediction to fuzzy relationship as yi=xi(1)o xi(2)o xi(3)oR

In this formulation the present magnitude is dependent on the previous magnitude and the time of event. Although this kind of relationship is desirable, but due to the complexity of computation within the framework of the probability theory, the Poisson process model is developed. A comparison has been made with published seismotectonic provinces results indicating good agreement, providing validation of the proposed model.

### A METHOD FOR EVALUATING UNCERTAINTY IN SEISMIC HAZARD BASED ON A MONTE CARLO APPROACH – ID 345

*T. Annaka, Tokyo Electric Power Services Co. Ltd., Japan*
*T. Suehiro, Tokyo Electric Power Co. Ltd., Japan*

We developed a logic tree model for evaluating uncertainty in seismic hazard for the Kanto district, Japan. Logic trees provide a useful tool for representing the uncertainties in the various model parameters. Although discrete branches with discrete probability distribution are usually defined for each node in the logic tree, the continuous probability distribution of the model parameter is also used for the node. In the present study we used both discrete and continuous distributions of the uncertain quantities. A Monte Carlo approach of randomly sampling the logic tree was used to simulate a distribution of seismic hazard curves.

For representing the seismic activity we used two types of seismic sources: (1) fault source generating large characteristic earthquakes, and (2) background seismic source generating small and moderate earthquakes. A characteristic earthquake model was used for fault sources. Logic trees for fault sources were developed for magnitude-frequency distribution, seismic source location and geometry, temporal model, and cascade model. A truncated Gutenberg-Richter recurrence model was used for background seismic sources. Logic trees for background seismic sources were developed for magnitude-frequency distribution and division of seismic source zones.

Logic trees for attenuation model for 5 % damped acceleration response spectra were also developed. The nodes are the selection of attenuation equation, site correction coefficient, and standard error of attenuation equation. Two types of distance measures, a shortest distance and an equivalent hypocentral distance from a site to a finite fault, were used as the branches. The uncertainty in site correction coefficient is represented by a normal distribution. Two branch models, magnitude dependent and magnitude independent models were used for the node of the standard error of attenuation equation.

Uncertainty in the hazard was evaluated based on the above logic tree model using a Monte Carlo approach and displayed by percentile hazard curves.

### HOW STOCHASTIC SIMULATION OF FAULT CASCADING CAN ASSIST TIME DEPENDENT EARTHQUAKE MODELING – ID 696

*M. Mahdyiar, AIR Worldwide Corporation, United States*

The rupture profiles of both recent and historic earthquakes indicate that fault cascading is a common phenomenon. It happens when adjacent faults or segments of a fault rupture as a unit. In time dependent hazard models, such scenarios would influence the recurrence rates of single segment ruptures and need to be considered in the time dependent analysis. A true time dependent fault rupture model is physically based. However, considering that most regional time dependent hazard analysis use renewal models, it is informative to investigate the effects of fault-cascading scenarios on stochastic time dependent analysis.

Formulating realistic fault-cascading scenarios has become an important consideration in constructing regional seismicity models. Typically, expert opinion in conjunction with geologic and seismologic information is used to formulate the potential cascading scenarios. Stochastic modeling can aid in the effort to quantify such information into probabilistic magnitude rate distributions for all possible rupture scenarios. We present a stochastic cascading

model for such a purpose. The model considers the uncertainties in the input parameters and fault interactions. The input parameters for the model are the slip rates or, alternatively, the recurrence rates of the characteristic earthquakes on causative faults. Geologic and seismologic information is used to constrain the model. The results are estimates of the magnitudes, rates, and corresponding uncertainties of all potential rupture scenarios that best represent the given information. We apply the model to the northern segments of the San Andreas fault system and investigate the sensitivity of the time dependent analysis to the input parameters and faults interaction assumptions.

### TIME, SPACE AND SIZE DISTRIBUTION OF EARTHQUAKES FOR FAGARAS SEISMOGENIC REGION (ROMANIA) – ID 845

*I. A. Moldovan, National Institute for Earth Physics, Romania*
*E. Popescu, National Institute for Earth Physics, Romania*
*O. Bazacliu, National Institute for Earth Physics, Romania*
*M. Radulian, National Institute for Earth Physics, Romania*

The probabilistic seismic hazard assessment (PSHA) in dense-populated geographical regions and subsequently the design of the strategic objectives are primary based on the knowledge of the seismicity parameters of the seismogenic sources which can generate ground motion amplitudes above the minimum level considered risky at the specific site. The PSHA deals with a Poissonian earthquakes distribution in space and time. This assumption implies the necessity of a catalog containing only independent events. For Romanian territory, besides the major impact of the Vrancea seismic region, characterized by strong intermediate-depth earthquakes, another important seismic source of crustal earthquakes is the Fagaras region, located in the Southern Carpathians, which should be taken into consideration when assessing the seismic hazard. The seismic regime of the region shows significant clustering effects related to earthquake generation together with quarry blasts generation. In order to study the time, space and size clustering of the seismicity, first we propose a method to discriminate the quarry blasts in the existing catalog. Second, we focused our analysis on the earthquake sequence generated near the Sinaia town in 1993, consisting of foreshock and aftershock sequences associated to a main shock of magnitude MW = 5.1. Fractal properties are investigated in the time, space and size distributions and their correlation. A few noticeable tendencies are outlined and discussed.

### SPATIAL VARIATION OF MAXIMUM CONSIDERED AND DESIGN BASIS EARTHQUAKES IN INDIAN PENINSULA – ID 957

*K. Jaiswal, Project Lead, RMSI Pvt. Ltd, India*
*R. Sinha, Professor, Dept. of Civil Engineering, IIT Bombay, India*

The importance of realistic seismic hazard assessment for earthquake safety has been realized for a long time. Rigorous efforts have been made during the last two decades in the scientific community to develop appropriate hazard assessment techniques on probabilistic framework suitable for prevalent tectonic conditions. This paper investigates the probabilistic assessment of seismic hazard associated with Peninsular India in terms of peak ground accelerations for different levels of ground shaking. It has been found that for many part of Peninsular India, the estimated seismic hazard is significantly higher than the specification in the current seismic zoning map of India given in Indian Standard code of practice for earthquake resistant design (IS 1893-2002). The investigation also indicates that there is substantial variation in the ratio of estimated peak ground acceleration for Maximum Considered Earthquake (MCE), that corresponds to 2% probability of excedence in 50 years, and for Design Basis Earthquake (DBE), that corresponds to 10% probability of excedence in 50 years, for most of the regions of Peninsular India. Such variations have not been considered in the current IS codes, which greatly influences expected structure performance after large earthquakes. It is also found that the MCE to DBE ratio is dependent upon the prominent seismotectonic zones of Peninsular India, which is very important criteria for assessment of long term seismic hazard for such moderately seismic regions.

### A PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF THE SUMATRA REGION, INDONESIA, USING STOCHASTIC MODEL – ID 1670

*D. Sandron, University of Trieste, Italy*
*P. Burton, University of East Anglia, UK*
*Y. Xu, University of East Anglia, UK*

The Sumatra earthquake (9.0 M, 26/12/2004) is one of the largest earthquakes in the world since 1900. This earthquake and its following tsunami killed nearly 300,000 people and caused heavy property losses in widespread areas around the Indian Ocean. This and the following triggered earthquake (8.7 M, Sumatra, 28/03/2005) both occurred in the Sunda trench - an important plate convergent zone, resulting from the movements between the India or Australia plate and the Eurasia plate. It is necessary to make the probabilistic seismic hazard assessments for this region in different ways because of its tectonic complexity and the variety of the rupture zones. This study primarily uses stochastic modelling to make the hazard assessment and compares these results with those from more traditional approaches.

The Monte Carlo modelling approach is used to evaluate the seismic hazard probability for the whole area. Based on analyses applied to the zones of aftershocks for the two recent strong earthquakes and the 1833, 1861, 1881 and 1941 large seismic rupture zones, the various probabilistic assessments for these zones are made. A further synthetic evaluation ensues and is also discussed.

The investigation continues by using different strong ground motion attenuation laws for this area and its neighbouring regions for the random simulations. These produce varied hazard evaluations and combined results for these are obtained using logic trees. Additionally, annual rates of seismic energy release (and equivalent magnitude), the maximum credible magnitude and the corresponding waiting time based on strain energy release analysis are also examined. These bring the parameter data set up to full strength for the above probabilistic seismic hazard assessments.

### PROBABILITY MODELS OF MODERATE EARTHQUAKES BASED ON THE GUTENBERG-RICHTER A AND B VALUES IN KANTO, JAPAN – ID 1702

*M. Imoto, NIED, Japan*

We attempt to construct models estimating probabilities of moderate size earthquakes (M>5.0) in Kanto, central Japan, with recurrent times of target earthquakes considered in reverse relation to the hazard. In estimating the recurrent times, the a and b values of the Gutenberg-Richter relation are estimated with micro-earthquakes and the relation is extrapolated to a magnitude range of targets. We consider two alternative cases; the case of the b value varying from point to point and the case of the b value remaining constant over the whole space under study. Retrospective analysis based on the catalogue of the NIED Kanto-Tokai network for the period from 1990 to 1999 indicates that the model with constant b performs better than that with varying b. This implies that the spatial variation in b will not work effectively for estimating earthquake probability. However, a comparison between the b value distributions during the background period and over a set of time-space points conditioned by target earthquakes suggests that some information could be obtained from the b value. In order to incorporate variations in b into the model with b remaining constant, a hazard function with a single parameter, b, is considered, in which a normal distribution is adopted and optimized to the data. The b value is distributed independently from the distribution of the a value. Appling these two parameters to the formula for earthquake probabilities by Aki, we obtain an earthquake probability model using both a and b values which performs better than either model of the Gutenberg-Richter relation, with constant or variable b

### TESTING AN ISING MODEL FOR PROBABILISTIC SEISMIC HAZARD ASSESSMENT – ID 1755

*A. Jiménez, University of Almeria, Spain*
*A. Posadas, University of Almeria, Spain*
*K. Tiampo, University of Western Ontario, Canada*

Previous works suggest that the seismic patterns can be modeled as a cellular automaton following an Ising interaction scheme. After a coarsegraining of the events, both spatially and temporally, a state (active or quiescent for seismic activity) is assigned to each cell at each time step. Then, a serial of lattice configurations (patterns) is obtained. Considering that each cell interacts only with its nearest neighbors, we can calculate the transition rules directly from these patterns. By maximizing the mutual information between the past and future states we can find the model which contains a higher correlation between the patterns. To accomplish this, a grid search in time steps and number of cells is made and, finally, we derive our cellular automaton. These rules have been proven to be similar to those of an Ising scheme, by using the Iberian catalog. In this work, more catalogs have been tested to confirm this behavior. Finally, the cellular automaton rules are applied to the latest pattern, and we obtain a Probabilistic Seismic Hazard Map, where the probability of surpassing certain energy (equivalent to certain magnitude) in the next interval of time is shown.

### APPLICATION OF BOOTSTRAP METHODS FOR INVESTIGATING THE TIME-VARYING STRUCTURE OF SEISMIC SERIES – ID 1879

*B. Orlecka-Sikora, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*
*S. Lasocki, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*

Widely known standard methods for resampling the statistical samples have been only recently developed into a new branch designed to operate on time series. In case of data dependent on time bootstrap sampling is carried out in a way that captures the dependence structure of the data. We use this "time-varying" bootstrap to investigate the temporal structure of earthquake catalogues from seismotectonically homogeneous areas of Greece. A block bootstrap method is applied to replicate the original seismic series preserving their dependence character. The replicas form a database for estimating the time dependent probability distributions. For this purpose both model and model-free approaches are applied. The time variability of the data is finally expressed by time changes of the probability distribution functions.

## SC-F 3: Multiparametric Test Sites in Europe for the Evaluation of Ground Motion Amplification

Level 2

### SEISMIC GROUND MOTION EVALUATION IN THE VALAIS : MODELLING AND RESPONSE SPECTRA – ID 308

*S. Alvarez-Rubio, SED-ETH, Switzerland*
*H. B. Havenith, SED-ETH, Switzerland*
*D. Fäh, SED-ETH, Switzerland*

In the frame of the SISMOVALP (Seismic Hazard and Alpine Valley Response Analysis) project, ground motion measurements, 2D-modelling and local hazard computations have been carried out for the Valais, the region with the highest seismic hazard in Switzerland. Here, we will focus on modelling aspects, computation of site response spectra and hazard spectra for 5 towns in the deep sediment-filled Rhone valley: Sion, Sierre, Visp, Martigny and Monthey. In order to evaluate amplification effects at these sites, 3 types of models had been used as inputs for seismic response simulations: a so called layered reference model M0 which is a general and realistic representative alpine valley that summarizes the main features detected in different alpine valleys under study; the 'Vetroz' and the 'Martigny' models representing the geology of the central/eastern (Sion, Sierre, Visp) and western part (Martigny, Monthey) of the Rhone valley, respectively. The seismic response is being computed by the use of the direct boundary element method (DBEM). The transfer functions as well as the time series obtained are discussed for different sites of these models in the scope of studying specific seismic site response in this type of valleys. The simulation outputs are also convolved with strong motion records (for hazard-characteristic magnitude-distance pairs) produced by stochastic simulation and downloaded from the European strong motion database. The results are compared with the regional hazard in terms of response spectra for rock and the specific sites.

### DENSE URBAN SEISMIC INSTRUMENTATION FOR SITE-EFFECTS ASSESSMENT IN BUCHAREST, ROMANIA – ID 518

*A. Aldea, UTCB/NCSRR, Romania*
*I. Okawa, Building Research Institute, Japan*
*S. Koyama, Building Research Institute, Japan*
*N. Poiata, National Center for Seismic Risc reduction, Romania*

In the frame of the Japan International Cooperation Agency JICA seismic risk reduction project in Romania, the National Center for Seismic Risk Reduction (NCSRR, Bucharest) instrumented in 2003 seven sites in the northern half of the capital of Romania, Bucharest. The JICA donated instrumentation (Kinemetrics) consists at each site of 3 triaxial sensors: one in free-field conditions and two in boreholes, one shallow borehole (around 30m depth) and one deep borehole (with depths ranging from 50m to 153m). The network already recorded 52 ground motions from 16 earthquakes with moment magnitudes ranging between 3.6 and 6, and the analysis of these data is presented in the paper. Recently another site was instrumented with Geosig equipments by Romanian efforts (triaxial sensors at free-field and in a 30m depth borehole). The seismic data is accompanied by velocity profiles at all the sites, determined by NCSRR in cooperation with Tokyo Soil in 2003-2005 by down-hole tests, using equipment donated by JICA. The NCSRR seismic network provides useful information for the site-response assessment in Bucharest. It also provides earthquake data allowing checking the amplifications due to the upper 30m of sediments, which is of interest for checking the site classifications and corresponding spectra from design codes. Located in Bucharest, a European capital-city with high seismic risk exposed to Vrancea subcrustal earthquakes, the NCSRR seismic network (with 15 instrumented boreholes at 8 sites where free-field sensors are also available) offers a valuable site for the evaluation of ground motion amplification.

### THE JANUARY 8, 2006 KYTHIRA (GREECE) EARTHQUAKE: MICROTREMORS AND BUILDING DAMAGES IN CHANIA (CRETE) – ID 1094

*F. Vallianatos, Technological and Educational Institute Crete, Greece*
*M. Moisidi, Brunel University, UK*
*P. Soupios, Technological and Educational Institute Crete, Greece*
*J. Makris, Technological and Educational Institute Crete, Greece*
*M. Mucciarelli, Università della Basilicata, Italy*

The effects of the local geology on ground motion amplification and the building damages in Chania as a consequence of the January 8, 2006 intermediate depth with epicentre East of Kythira (Southern Greece) and magnitude 6.9 are studied. In this direction a geological survey was performed, microtremor and refraction microtremor measurements were recorded. A dense microtemor survey of about 500 measurements was performed in the city of Chania focused in the historical center within the Venetian Walls of the 15th century with great historical and architectural value. The innovative HVSR Technique has been adopted since it is a

non-invasive and precise technique for damage estimation in urban areas. Three main families of resonance frequency were obtained. In some cases HVSR spectral ratios shows multiple peaks due to the presence of complex subsurface structure. Furthermore, the Refraction Microtremor Technique as proposed by Louie (2001) and Lai and Rix (1998) was also applied. This method is based on a) common seismic refraction recording equipment, and (b) on a simple, two dimensional slowness-frequency transform of a microtremor record that separates Rayleigh waves from other seismic arrivals and allows recognition of the true phase velocity against apparent velocities. Nineteen sites in the broader area in Chania were measured in order to make a classification and a preliminary evaluation of shear velocity in the near surface structure. Using data from a reconnaissance survey on building damages in the city of Chania (Crete, Greece) after the January 8, 2006 Kythira earthquake, a comparison of the HVSR and Vs30 results with the spatial distribution of damages in Chania is presented.

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### SITE EFFECT INVESTIGATION AT THE TITO TEST SITE (SOUTHERN ITALY) – ID 1720

*S. Parolai, GFZ, Germany*
*M. Mucciarelli, USB, Italy*
*R. M. Gallipoli, IMAA-CNR, Italy*
*S. M. Richwalski, GFZ, Germany*
*A. Strollo, GFZ, Germany*

The town of Potenza (Southern Italy) was chosen as one of the Italian test sites for preparing ground motion scenarios within the framework of the DPC-INGV 2004-2006 projects. Just next to the town, the village of Tito was selected as a test area where different techniques for estimating site effects are to be applied and evaluated. Therefore, a 30 m deep borehole was drilled and down-hole measurements performed. In a first time a Kinemetrics SBEPI + K2 (borehole) and a STS2 + Q3300 at the surface were installed in order to record seismic noise as well as local, regional, and teleseismic events. From June 2005 the data were recorded by the Episensor at the surface, linked to the 6 channel K2. Furthermore, three seismological micro-arrays (utilising short period sensors and digitizers with high dynamic range) were installed in May 2005 for recording seismic noise. Different acquisition geometries were used in order to check any dependency of the derived dispersion curves on the adopted analysis method (ESAC, F-K) In general, the ESAC method seems to provide more reliable results in the low frequency range. Furthermore, the soil velocity profiles obtained from the micro-array data were compared with the S-wave velocity profile derived from the down-hole measurements. A good agreement was observed in the valid depth range. Finally, empirical site responses were compared with those calculated numerically from the S-wave velocity profiles obtained from micro-array data.

### TEST SITES IN EUROPE FOR THE EVALUATION OF GROUND MOTION AMPLIFICATION: SITE RESPONSE OF THE GUBBIO BASIN (CENTRAL ITALY) USING WEAK MOTIONS RECORDED BY LINEAR SEISMIC ARRAYS – ID 1770

*F. Cara, INGV, Italy*
*S. Parolai, GFZ, Germany*
*G. Monachesi, INGV, Italy*
*R. Milkereit, GFZ, Germany*
*E. Günther, GFZ, Germany*
*G. Di Giulio, INGV, Italy*
*G. Milana, INGV, Italy*
*D. Bindi, INGV, Italy*
*A. Rovelli, INGV, Italy*

The plain of Gubbio is located in a northwest-southeast oriented, 4-km wide, 20-km long intermountain basin in the northern Apennines, central Italy. The moderate-magnitude earthquakes of the 1997 Umbria-Marche seismic sequence, occurred 40 km southeast of Gubbio, generated displacements as large as 6 cm within the basin. The large amplitude phase, not observed outside of the basin, was followed by low-frequency wave trains lasting up to 1 minute. In order to investigate the mechanism of possible local amplification effects, different kind of geophysical and geological investigation of the basin started within the framework of the Italian DPC-INGV projects. In particular, the GFZ and the INGV deployed two linear seismic arrays. The first one was composed of ten seismological stations with 1-s receivers. It operated from June until December 2005. The array was oriented north-south, approximately: all the stations but two were installed on the sedimentary deposits. The remaining two stations (the northernmost and the southernmost) were installed on rock outcrops at the edges of the basin. The second array, composed by 10 stations with 5-s receivers, was deployed along the main axis of the basin, and is recording since November 2005. For 45 days, the two arrays worked simultaneously. A selected dataset of 250 earthquakes has been analyzed. H/V spectral ratio results show that systematic low-frequency (0.3-0.4 Hz) amplification affects the stations in the middle of the basin. The resonance frequency peaks are consistent with the thickness and the average S-wave velocity of soft sediments derived from microtremor measurements in the basin. The conventional spectral ratio results show a more complex broad-band (0.3-10 Hz) amplification. The analysis of selected records by means of a sonogram approach highlights the arrival of strong late phases increasing the signal duration at the stations located in the middle of the basin.

### TEST SITES IN EUROPE FOR THE EVALUATION OF GROUND MOTION AMPLIFICATION: SITE RESPONSE OF THE GUBBIO BASIN (CENTRAL ITALY) USING GEOLOGICAL DATA AND SEISMIC NOISE MEASUREMENTS – ID 1858

*V. D'Amico, Dip.Scienze della Terra - Università di Siena, Italy*
*M. Picozzi, Dip.Scienze della Terra - Università di Siena, Italy*
*F. Baliva, Dip.Scienze della Terra - Università di Siena, Italy*
*D. Albarello, Dip.Scienze della Terra - Università di Siena, Italy*
*M. Menichetti, Dip.Scienze della Terra - Università di Urbino, Italy*
*F. Bozzano, Dip.Scienze della Terra - Università di Roma 1, Italy*
*S. Martino, Dip.Scienze della Terra - Università di Roma 1, Italy*
*S. Rivellino, Dip.Scienze della Terra - Università di Roma 1, Italy*
*G. Scarascia Mugnozza, Dip.Scienze della Terra - Università di Roma 1, Italy*

We present results so far obtained by an extensive study aiming at the geostructural and seismic characterization of an intra-Apenninic sedimentary basin in the frame of a research project, financed by the Italian Department of Civil Protection, devoted to assess ground shaking scenarios at some test sites in Italy. Main objective of the research is the definition of the geometry and a first order 1D characterization of the local seismic response of the Gubbio basin. This basin is a typical half-graben originated by a SW dipping listric normal fault which borders it on the E flank, filled up to about 400 m by continental sediments of Quaternary age. To characterize such sediments, data from 100 bore-holes were processed. In the central and NE sector, are present gravelly deposits (in alluvial fans facies) interefingered with debris fans, whereas in the SW sector sands and clays of fluvio-lacustrine environment are prevalent. To constrain the geometry of the soft sedimentary coverage and to supply first order information about its Vs velocity structure, a number of ambient noise measurements has been carried on. In particular, over than 100 sites have been considered for single station measurements. At these sites, resonance frequencies have been estimated by the HVSR technique. Along these measurements, bidimensional array noise recording have been carried on at a number of sites to constrain the local S-wave profiles up to 50-100 m depth. The joint analysis of these measurements allowed a first first-order reconstruction of the basin geometry. Furthermore, it has pointed out the presence of clear resonance phenomena inside the plain area and close to a large part of the basin edges, in the frequency range of 0.4-0.8 and 1-10 Hz, respectively. Significant resonance phenomena lack instead inside

the historical centre of Gubbio and along the northeastern edge of the plain.

## SC-F 4: Geoinformation Technologies Oriented to Seismic Hazard and Seismic Risk Assessment

Level 2

### MANAGEMENT AND AIDED DECISION MAKING SYSTEM FOR EARTHQUAKE DISASTER REDUCTION BY MEANS OF A WEBGIS – ID 168

*Y. Baohua, Earthquake Administration of Shanghai Municipality, China*
*S. Wenzhong, Hong Kong Polytech Univ, China*
*T. Xiaohua, Tongji University, China*

A methodology for establishing a general framework of the information management and aided decision making system for earthquake disaster reduction by means of a WebGIS is presented in the paper. The architecture, function, design criteria, data collecting, spatial analysis and operation procedure of the system are all introduced in detail. The information system for earthquake disaster reduction has a three-tier architecture consisting of expression service, middleware, and data service tiers. The system database is composed of four sub-databases: a seismic and geological database, an engineering environmental database, a disaster relief resource database and an analysis result database. The methods of establishing database, analyzing earthquake risk, estimating construction vulnerability, predicting earthquake damage, analyzing scenario earthquake and earthquake influence field, quantifying economic losses and casualties caused by earthquakes, making aided decision for post-earthquake emergency response are studied by means of a GIS. These methods were carried into execution in the form of the function components in the middleware tier. In order to further analyze earthquake data, the foundational information module, the earthquake loss module and the emergency response module are designed on the client side by using WebGIS technology. In addition, key technologies used for establishing the information system, for instance, middle-component technology, optimizing attemperation technology for spatial data, balance technology between vector transfer and raster transfer for spatial data, are also introduced. These techniques ensure that the system is advanced and practical. In the information system established by using above technologies, the information about earthquake disaster reduction can be shared, and the earthquake disaster data can be all-around analyzed. Aided decision making for post-earthquake emergency response can be made. Finally, Daqing City in China was selected to be the area of case study, the above methods and technologies were confirmed in the case study. Good results were obtained.

### HAZUS-MH ADAPTATION FOR EARTHQUAKE LOSS SCENARIOS IN SWITZERLAND – ID 785

*B. Duvernay, Federal Office for the Environment, Switzerland*
*C. Herold, GRID, Switzerland*
*O. Lateltin, Federal Office for the Environment, Switzerland*

HAZUS-MH is a loss estimation GIS-tool distributed by the American Federal Emergency Management Agency (FEMA). It is capable of generating loss estimations within the US territory for earthquake, flood and wind scenarios. The types of losses calculated by the model are direct human casualties, direct physical damage to buildings and lifeline elements as well direct financial and indirect financial losses.

The adaptation of the earthquake module of HAZUS for Switzerland has been initiated by the Coordination Center for Earthquake Risk Mitigation of the Swiss Federal Office of the Environment. The principle of the adaptation was accepted by FEMA under the restriction that the source code would not be accessible. Even with this limitation and the absence of guidelines, all functions of the earthquake module could be adapted.

For the generation of shaking maps (hazard module), attenuation functions from the US west coast region that agree reasonably enough with the attenuations functions proposed by the Swiss seismological service can be directly used. Existing soil class maps according to the Swisscodes can also be imported and used with corresponding amplification factors.

For the generation of losses (loss module), a research project with the Federal Institute of Technology of Lausanne started in 2005 in order to verify and if necessary modify the fragility functions according to the structural characteristics of the existing buildings in Switzerland. The project is focusing at first on modern masonry buildings, which represent a high percentage of existing buildings in Switzerland.

In 2005 as well, the population database and national level databases (level 1) for general building stock distribution in occupancy classes were created based on national census and cantonal insurances data. Regional inventory studies will be launched in 2006 in order to better capture the distribution of the general building stock in structural classes.

### SEISMOLOGICAL KNOWLEDGE REPRESENTATION WITH BDSIS – ID 1471

*P. Gueguen, LGIT, France*
*C. Pequegnat, LGIT, France*

BDsis is a toolbox dedicated to the exploitation of the knowledge implied in the treatment and the distribution of discrete or continuous set of seismological data. The core of the system is a relational database (about 40 tables) which contains all the information necessary to the representation of : acquisition chains (from the installation sites with their external carateristic to the material components of the channels with their instrumental answers), events (localizations, magnitudes, picks – theoretical and observed), records (format, size, max value,...) The various tools associated with this base are directly usable java pluggin : a WEB service for distribution: distriBDsis, which makes it possible for a user to find records on the basis of criterion magnitude, amplitude, épicentrale distances, etc. Information is presented here in textual form. a geographical WEB service for representation of the stations - events relation for the selected records : cartoBDsis. Moreover, this service provides the representation of the data in PGA-graph forms and allows for the interactive generation of reports which contain the geographical and graphic representations of the selected data a graphic user interface: inBDsis which, when associated with a set of lower level commands, facilitates the installation of a BDsis database. We will currently present one of the implementations of BDsis used for the French Permanent Accelerometer Network. This dataset consists in a collection of records produced since 1995 (to date) by approximately 150 stations in France and in the Antilles.

## SC-F 6: Geophysical and Civil Engineering Aspects of Hazard, Risk, and Mitigation for Major European Cities

Level 2

### THE METHODOLOGY FOR PROBABILISTIC SEISMIC RISK ANALYSIS BASED ON EARTHQUAKE CONSEQUENCE – ID 352

*Z. Wen, Institute of Geophysics, CEA, China*
*Y. X. Hu, Institute of Geophysics, CEA, China*

A method is proposed for a probabilistic seismic risk analysis for a structure located at specified site directly considering probability of earthquake events, and the associated consequences (damage or loss) over the defined time period other than implicitly inferring seismic risk by estimating probabilistic seismic hazard and translating the results of PSHA into seismic risk. It can be

determined the adverse consequences that structure, people and society might suffer as a result of future earthquakes, and estimated the probability of these consequences for some future time period, Which is defined in terms of a suite of seismic risk curves that shows the probability of exceeding different levels of consequence levels at the site during a specified period time. The most direct way to make probabilistic estimates of seismic consequence (damage ratio, economic loss ratio) is represented as a function of earthquake magnitude, source location and type of soil condition. Then seismic risk is aggregated directly combining uncertainties in the size, location, rate of occurrence of earthquakes, and the variation of consequence probability distribution with earthquake size and location. This allows the temporal and spatial probabilistic pattern of all events from small to large size to be modeled and can be capable of handling uncertainties associate with all the components of risk model. As an illustration of the procedure, the seismic risk analysis of a site is presented.

### JICA TECHNICAL COOPERATION PROJECT FOR SEISMIC RISK REDUCTION IN ROMANIA – ID 510

*R. Vacareanu, Technical University of Civil Engineering, Romania*
*T. Kaminosono, National Center for Seismic Risk Reduction, Romania*

JICA Technical Cooperation Project on Reduction of Seismic Risk for Buildings and Structures started in Romania on October 1st, 2002. The scope of the Project is to strengthen the capacity of earthquake related disasters prevention activities in Romania. The Project is the output of four years of intensive efforts made by professionals from Technical University of Civil Engineering Bucharest – UTCB, Ministry of Transport, Constructions and Tourism, Romania, National Building Research Institute - INCERC Bucharest, Japan International Cooperation Agency - JICA, Building Research Institute, Tsukuba and National Institute for Land and Infrastructure Management, Tsukuba, Japan. The duration of the Project is five years. The schedule is as follows: (i) First year: investigation of Romanian evaluation and retrofitting techniques; study of Japanese evaluation and retrofitting techniques; (ii) Second year: collection of existing data on strong Romanian earthquakes, soil properties and vulnerable buildings; (iii) Third year: performing structural tests and soil investigations; (iv) Forth year: drafting of technical manuals on building seismic evaluation and retrofitting and on seismic ground motion evaluation; (v) Fifth year: reviewing and issuing of technical manuals on building seismic evaluation and retrofitting and on seismic ground motion evaluation. The implementing agency of the JICA Project is the National Center for Seismic Risk Reduction, NCSRR. The activities are carried out by NCSRR in partnership with UTCB and INCERC by jointly organizing testing laboratories and facilities. During the Project period, 24 young Romanian engineers are trained in Japan, 3 Japanese long-term experts and 26 Japanese short-term experts work in Romania. Equipments for seismic instrumentation of the Romanian territory, dynamic characterization of soil and seismic testing of structures rising up approximately to 2.20 million USD is donated by JICA to Romania, through NCSRR. The paper describes the main activities and results of the JICA Project within the first three years.

### A NEW DIGITAL SEISMIC NETWORK IN ROMANIA WITH DENSE INSTRUMENTATION IN BUCHAREST – ID 515

*A. Aldea, UTCB/NCSRR, Romania*
*T. Kashima, Building Research Institute, Japan*
*N. Poiata, National Center for Seismic Risk Reduction, Romania*
*T. Kajiwara, OYO Corp., Japan*

In 2002 the National Center for Seismic Risk Reduction (NCSRR, Bucharest, Romania) was created under the umbrella of Ministry of Transports, Construction and Tourism, in order to implement the Japan International Cooperation Agency Technical Cooperation Project with Romania entitled "Seismic risk reduction for buildings and structures". Within this Project JICA donated Kinemetrics seismic instrumentation and sent specialists from OYO Corp. for the installation. The donated seismic network is divided in three types of instrumentation that are described in the paper: (i) free-field - outside Bucharest (6 accelerometers), (ii) building - in the capital city Bucharest (4 buildings), and (iii) free-field and borehole in Bucharest (7 sites, each site having a free-field sensor and two instrumented & 14 boreholes ranging from 24m to 153m depth). The NCSRR seismic network was installed in 2003. In 2004 it was enlarged with Romanian investment, and a new site was instrumented in Bucharest at free-field and in one borehole with Geosig instruments. In 2005 the Center purchased other 4 seismic stations, one installed in a building in Bucharest and 3 stations outside Bucharest in free field conditions. Since it's installation the NCSRR network recorded more than 60 seismic motions from 17 earthquakes with moment magnitudes ranging from 3.6 to 6.0. From these earthquakes 15 are from Vrancea subcrustal source, one from a shallow source in Eastern Romania and one from a shallow source in Bulgaria. Examples of recorded and processed data from the strongest event (Mw=6.0, h=99km) occurred on October 27, 2004 are also presented in the paper, together with a synthesis of all recorded motions.

### SEISMIC MICROZONATION OF THE CITY OF BUCHAREST – ID 993

*D. Lungu, UTCB/INCERC, Romania*
*C. Arion, NCSRR/UTCB, Romania*
*E. Calarasu, INCERC/NCSRR, Romania*

The experience obtained worldwide regarding earthquakes occurred in the last decades has shown the variability with local soil conditions of seismic motion characteristics. Phenomena of differentiated seismic amplification as a function of superficial geology were observed in Romania and in the capital city of Romania, Bucharest, during the 1977, 1986, and 1990 Vrancea earthquakes as well as in other more recent Romanian earthquakes. As compared to the rest of the country, with a population of more than 2 million inhabitants, Bucharest collected the most significant losses during the Mw=7.5 Vrancea earthquake of March 4, 1977, 1424 people dead and 32 tall Reinforced Concrete buildings collapsed. Based on the available data obtained from more than 400 boreholes and using the GIS techniques, significant soil parameters were mapped for the territory of Bucharest. The geological results, correlated with (i) shear wave velocity measurements in several locations having depth between 30 m and 200 m and (ii) recorded seismic data processing, permits seismic microzonation of Bucharest to be used as a tool for urban planning and earthquake risk reduction.

### PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR VRANCEA EARTHQUAKES AND SEISMIC ACTION IN THE NEW SEISMIC CODE OF ROMANIA – ID 1003

*D. Lungu, UTCB/INCERC, Romania*
*S. Demetriu, UTCB/NCSRR, Romania*
*A. Aldea, UTCB/NCSRR, Romania*
*C. Arion, NCSRR/UTCB, Romania*

The new edition of the code for design of earthquake-resistant buildings and structures in Romania P100 was issued in 2005. This code will be enforced during this year and follows the format and contents of Eurocode 8. The paper presents the background of probabilistic seismic hazard analysis used for constructing the actual seismic hazard map of Romania: recurrence of magnitudes, attenuation equations for peak ground parameters, spectral ordinates and seismic intensity, sensibility of results with focus depths and max. credible magnitude of the source, etc. A discussion on previous world-wide hazard studies for subcustral events and on the corresponding attenuation laws is presented with comments. The paper also presents the response spectra corresponding to various soil types and recommends the design spectra to be used in the case of the shallow seismic sources in western Romania. The ground conditions in Romania are divided into various categories using as the descriptor of the frequency

contents of the local ground motion, the corner period of response spectra ,Tc. The seismic design code will be used within the new set of Romanian codes: Basis of design, Wind action and Snow action. The new set of codes has been prepared in 2005 at UTCB, Technical University of Civil Engineering Bucharest following the Eurocode 0 and Eurocode 1 format and data.

### OVERVIEW OF SITE EFFECT STUDIES IN ISTANBUL – ID 2018

*O. Ozel, Istanbul University, Turkey*
*E. Durukal, Bogazici University, Turkey*
*M. Erdik, Bogazici University, Turkey*

In 1999, a devastating earthquake struck the Kocaeli, Adapazari provinces, and part of suburbs of Istanbul, a densely populated region in the industrial heartland of Turkey. Following the losses caused by this earthquake, there has been a broad recognition among Turkey's governmental, non-governmental and academic organizations of the need for response planning based on detailed risk analysis of likely seismic hazard, microzonation studies and ground-motion researches in Istanbul. Bogazici University's Department of Earthquake Engineering (KOERI) carried out an urban earthquake risk assessment study for Istanbul with the support of International Red Cross/Turkish Red Crescent. The metropolitan municipality of Istanbul implemented a project on disaster mitigation basic plan in Istanbul. The objective of this project was to develop seismic microzonation maps which will serve as the basis for disaster mitigation plan for Istanbul. KOERI installed the Istanbul Earthquake Rapid Response and Early Warning system (IERRS) in the metropolitan area with the aim of providing real-time damage maps to third parties right after an earthquake. In addition to these activities substantial effort has been devoted to the analysis and interpretation of field-data in view of earthquake source parameters, source models, local site effects and near-field effects for both past events and also for future earthquakes, particularly for scenario earthquakes representative of the expected large earthquake on the Marmara fault. Furthermore, CEDIM of Germany and KOERI have been implementing a multi-disciplinary project. One of the aims of the project is to improve the knowledge about the influence of local geology in Istanbul. Both single station and array measurements of microtremors noise were conducted at each IERRS site. In a district of Istanbul, a vertical array was installed that consisted of a four level layout at 25, 50, 75 and 150m depths. In-situ and lab experiments were conducted for geotechnical characterization of soil strata.

## SC-F 7: Potential for Very Large Earthquake Disasters in the European Mediterranean Region

Level 2

### ASSESSMENT OF EARTHQUAKE RISK IN URBAN SPACES – ID 1599

*H. Javaheri, University of Tehran, Iran (Islamic Republic Of)*
*A. Abiri Jahromi, University of Tehran, Iran (Islamic Republic Of)*
*F. Saifoldini, University of Tehran, Iran (Islamic Republic Of)*
*A. Falahi, University of Tehran, Iran (Islamic Republic Of)*

Earthquake risk indicates its direct derived damages in urban spaces. While urban conditions indicate difficulty in relief vacating and mission when Earthquake is happened. Therefore classifying danger and damage of earthquake and urban conditions can help to experts and decision makers for assessing danger and damage of earthquake. In this paper, we tried to assess earthquake risk in Tehran Municipality. Therefore first, we examinant damage of earthquake in urban regions of Tehran Municipality by physical indicators (average of earthquake intensity, damaged residential buildings and approximate casualties in each region) and urban indicators (density of population, outdoor area narrow way ratio to total area in each region). Then Tehran Municipality is divided to 3 zones (low, medium and high level) regarded to damage of earthquake. Consequently it's offered recommends about responding to earthquake risk in this Municipality.

### LOWER TAGUS VALLEY, NEAR LISBON: LOCAL SOURCES VERSUS DISTANT OFFSHORE SOURCES – ID 1773

*J. Fonseca, Instituto Superior Tecnico, Portugal*

Lisbon is strongly associated with earthquake disasters, due to the 1755 Lisbon earthquake and its enormous impact. However, there is a widespread conviction that such a large event ( M8.5) in a region of slow deformation such as western Iberia ( 5mm/y of convergence between the African and Eurasian plates) has to be very rare, with several centuries or millennia to come before its repetition. Already a highly developed region, the Lower Tagus Valley continues to develop fast, with large new projects for international airports, high velocity trains, power plants, etc, without a careful discussion of the associated seismic risk. But the historical seismicity of the region reveals a significant level of seismic activity with local source, currently referred to as the Lower Tagus Valley Fault System. The associated active faults remain mostly unknown, preventing an adequate assessment of the seismic hazard. The emphasis put, due to historical reasons, on offshore sources of very large earthquakes may be a distracting factor as far as the importance of the local sources is concerned. This paper reviews the destructive historical earthquakes with probable source in the Lower Tagus Valley, and attempts to improve the characterization of the seismogenic activity with paleoseismological data. On a shorter time scale, PSInSAR data is used to investigate the current rate of aseismic deformation, and discuss its possible meaning. The apparent contradiction between the intraplate deformation rates in western Iberia and the slow convergence rate of the surrounding plates is discussed.

### MODELLING DAMAGE AND TSUNAMI SCENARIOS OF THE 1755 GREAT LISBON EARTHQUAKE – ID 1778

*M. J. Jimenez, Institute of Earth Sciences "Jaume Almera" CSIC, Spain*
*F. Vaccari, Department of Earth Sciences, University Trieste, Italy*
*M. Garcia-Fernandez, Institute of Earth Sciences "Jaume Almera" CSIC, Spain*
*F. Romanelli, Department of Earth Sciences, University Trieste, Italy*
*T. Pinat, Department of Earth Sciences, University Trieste, Italy*
*G. F. Panza, Department of Earth Sciences, University Trieste, Italy*
*J. M. Martinez-Solares, 3. Instituto Geográfico Nacional, Spain*

The great historical earthquake occurring on Saturday November, 1, 1755 caused an immense social impact at the time not only in the Iberian Peninsula but also all over Europe. The earthquake known as the great 1755 Lisbon earthquake because it destroyed the city of Lisbon occurred offshore the Iberian Peninsula.

The earthquake caused highest damage in Lisbon and in the Algarve (south Portuguese coast) and was followed by a tsunami affecting the North Atlantic coasts from UK to Morocco.

In recent time the interest on the great Lisbon earthquake has increased and a number of studies have been carried out based on different approaches and data and published in the last years. Still there is some controversy when trying to answer questions such as: Where was the earthquake located?, Was the damage and associated tsunami reported due to one or more earthquakes? What was the size of the earthquake? Which seismogenic source can be the earthquake associated to? What was the source mechanism of the event?

A number of plausible locations for the source have been proposed since the early works at the beginning of last century, including locations close to that of the Mw 7.8 1969 event SW of Cape S. Vicente. Some authors have proposed the triggering of an inland earthquake just after the offshore event and also a composite source incorpo-

rating the Marques de Pombal thrust fault and the Guadalquivir Bank.

The aim of our study is to combine the use of all available and most recent information from geology, seismicity, and historical records on damage and tsunami effects with the modelling of ground motion and tsunami scenarios to discuss plausible source characteristics consistent with the available data.

### SOME UNUSUALLY STRONG, HISTORICAL EARTHQUAKES IN GREECE – ID 1894

*S. Stathis, Dept. of Civil Engineering, Patras University, Greece*

Three earthquakes, two regionally destructive events originating along the Hellenic Arc, and one from the back-arc region are examined. First, a circa 200BC in Rhodes Island earthquake, associated with >3m uplift which destroyed the ancient military harbour, some ramps of which are presently found several meters above sea-level. Elastic dislocation analysis revealed that coastal uplift is related to a reverse fault controlling a 4.5km deep marine basin and the emergence of the whole of the island. This earthquake seems to have been an event much larger than certain magnitude 7.5 earthquakes, occurring every 100-200 years or less, sometimes associated with tsunamis and affecting the Eastern Mediterranean. Second, the AD365 earthquake, associated with a tsunami which destroyed parts of Egypt and its anniversary was commemorated for centuries as the Day of Horror. Coastal data and historical evidence indicate that this earthquake was associated with the up to 9m coastal uplift of Crete and large scale destruction in an East Mediterranean scale. Elastic dislocation analysis permitted to identify that this earthquake, of min magnitude 8.5, was related to a >200km long fault and a bathymetric escarpment. Third, an earthquake in the Gulf of Corinth, associated with considerable coastal uplift in a terrain characterized by small normal faults. This earthquake caused major destruction and uplift of the only harbour in the area, presently 4m above its initial elevation, condemning it to decline. In an adjacent rock, analysis of biological remains indicate an average uplift rate of >3mm/yr for the last 8,000years. Such earthquakes, basically deduced from coastal and archaeological data, indicate that Greece and the Eastern Mediterranean are affected by some strong events, much stronger than those deduced from historical and instrumental data, to which the seismological studies in Greece are usually based.

### EARTHQUAKE POTENTIAL OF SEISMOGENIC ZONE – ID 1992

*V. Schenk, Inst.of Rock Structure & Mechanics, Acad.Sci., Czech Republic*
*Z. Schenková, Inst.of Rock Structure & Mechanics, Acad.Sci., Czech Republic*

Suggested procedure allows the present earthquake potential of any seismogenic zone to be evaluated. It is based on an existence of an earthquake catalogue that has to contain data on historical and recent events relatively homogeneous in earthquake positions and sizes. Seismogenic zones should be delineated by means of all available geological materials and geophysical data to put maximally together the events of the same seismogenic origin. From the events located in the seismogenic zone under study the Benioff graph of energy release is compiled. It allows probabilities of possible earthquake occurrences and their magnitudes to be assessed. Probability classes for both phenomena mentioned above are delivered and a few examples of seismogenic zones of Central Greece are discussed.

## SC-F 8: Near Real-Time Damage and Loss Assessment due to Strong Earthquakes

Level 2

### DAMAGE DETECTION FOR THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE USING SATELLITE SAR – ID 735

*M. Matsuoka, Earthquake Disaster Mitigation Res. Ctr., NIED, Japan*
*K. Horie, Earthquake Disaster Mitigation Res. Ctr., NIED, Japan*
*H. Ohkura, Nat. Res. Inst. Earth Sci. & Dis. Prev. (NIED), Japan*
*F. Yamazaki, Chiba University, Japan*

Recent earthquakes like the 1994 Northridge and the 1995 Kobe earthquakes, highlight the importance of obtaining damage information for built-up areas at an early stage in order to assist resuming normal activities and for future recovery planning. Synthetic aperture radar (SAR) has remarkable capability to record the physical values of the earth's surface, regardless of weather conditions or the amount of sunlight. Building damage detection technique has been successfully applied to past earthquakes such as the 1995 Kobe and 2003 Bam, by using the compound index, which is the value derived from the correlation and difference in intensities between pre- and post-event images. This technique was applied to the affected areas due to the 2004 Niigata-ken Chuetsu earthquake on October 23, 2004, by using one pair of Radarsat images taken after the earthquake (October 25, 2004) and before the earthquake (October 1, 2004). However, it was not possible to identify any significant distribution of damaged buildings. In this study, we propose a new technique by using two pairs of SAR images, to identify smaller building damage ratios compared to previous techniques. The main idea is to minimize the effect of signal noise and temporal changes of the earth's surface, on building damage estimation, by calculating the difference values from the two pre-event images and one post-event image. In a macroscopic point of view, the distribution of the deference value of correlation coefficient in built-up areas is in good agreement with damage by survey reports. In Yamakoshi village, located in highland, we also could also identify large-scale landslides with accuracy as good as interpretation from aerial photos.

### INTERPRETATION OF EXPRESSWAY DAMAGES IN THE 2004 MID NIIGATA EARTHQUAKE BASED ON AERIAL PHOTOGRAPHS – ID 738

*Y. Maruyama, Chiba University, Japan*
*F. Yamazaki, Chiba University, Japan*
*H. Yogai, Central Nippon Expressway Co., Ltd., Japan*
*Y. Tsuchiya, Central Nippon Expressway Co., Ltd., Japan*

In the Mid Niigata earthquake, which occurred on October 23, 2004, the expressways were closed just after the earthquake. Many major and minor damages were caused because of this earthquake. The traffic regulation was continued, and the expressway was tentatively re-opened on November 5. It took about a month to open the regular four-lane road. In Japan, it is anticipated that the Tokai earthquake is coming and many severe damages are caused in various infrastructures. The expressway network will be subjected to severe ground motion in the Tokai earthquake. From this viewpoint, it is important to grasp the damages of expressways at an early stage just after the earthquake so as to make an efficient traffic control and a rapid disaster response. The remotely sensed imagery data obtained from satellites and airborne platforms are effective to grasp damage distribution due to natural disasters. In the 2004 Mid Niigata earthquake, various organizations have investigated the possibility to grasp the damage distribution based on remote sensing technology. In this study, visual damage inspection is conducted using aerial photographs taken by Geographic Survey Institute, Japan. Based on the field photos taken by Central Nippon Expressway Co. Ltd., the degree of damages that can be detected by aerial photographs is discussed. In addition that, image data processing is performed to identify the damaged sections of the expressways. It is expected that this

technique will be applied to the automated damage detection of the expressway networks.

### DAMAGE ESTIMATION AND RESPONSE SIMULATION IN THE INTEGRATED EARTHQUAKE DISASTER SIMULATION SYSTEMS – ID 742

*N. Kodama, NIED, Japan*
*Y. Goto, NIED, Japan*
*S. Kakumoto, NIED, Japan*
*I. Takeuchi, NIED, Japan*

Our studies on "Integrated Earthquake Disaster Simulation Systems (IEDSS)" started in a special project funded by Japanese Government in 2002. IEDSS are comprehensive systems for disaster mitigation, those main two components are the spacial-temporal geographic information system (GIS) for local governments and the disaster information center system. The former system has functions for district information management and disaster information gathering, and helps with disaster response of local governments. And the latter one has functions for detailed damage estimation, disaster response simulation and wide area image processing such as aerial photos or satellite images, and helps local governments with disaster information processing from outside of the disaster site. We report here the progress in development of damage estimation and disaster response simulation programs, and also the spacial-temporal GIS-based information provided to local governments. Those are the main important functions of the disaster information center system, and can be used not only for informed decision making but also for city planning intended to mitigate the risk and disaster drill planning. The damage estimation procedures followed by disaster response simulations will be executed in the system. In a prototype system currently being developed, the damage estimation functions include the following: earthquake motion, liquefaction, individual building damage, lifeline damage, bridge damage and road blockage after collapsed buildings. And the disaster response simulations include the following: fire spread, plant fire spread, transportation, search and rescue, fire fighting and evacuation.

### IMPLEMENTATION OF THE MUNICIPALITY EARTHQUAKE DISASTER PREVENTION INFORMATION SYSTEM BASED ON RARMIS – ID 743

*H. Yamada, NIED, Japan*
*T. Furuto, NIED, Japan*
*N. Sasaki, NIED, Japan*
*K. Fukuyama, Mie nuiv., Japan*
*S. Kakumoto, NIED, Japan*

The aim of this study is to establish the municipality earthquake disaster information system based on RARMIS (Risk Adaptive Regional Management Information System) concept that achieves disaster reduction by the solution of information problem. It is important to design the system that the function of ordinary operation is able to correspond in emergency, and it is shown to be able to construct the system satisfy the concept of RARMIS. This concept is achieved seamless cooperation in ordinary and emergency, spatial-temporal information processing and decentralized and independent information processing. Certain operation for the earthquake disaster, it is need to functions surely when municipality facilities suffer from earthquake disaster. It is important for them to have a cost-benefit performance, and not required expense for earthquake-resistant equipment. The development system that consists of "Disaster Prevention Information Center System" that does information processing of innovative technique and expertise, and "Municipality Spatial Temporal Information System" that processes regional information of disaster as seamless extension from daily work was constructed. This system implemented the Mie Prefecture Seismic Disaster Prediction System that system is composed of a disaster information center system and real-time earthquake damage prediction systems for municipality. In this study, the support for recovery service was conducted at the municipality in the disaster area of the Niigata-ken Chuetsu earthquake in 2004. Latent information problem was given from support activity at the actual operation. Municipality Spatial Temporal Information System was presented as a problem solving method, and then the practice support to achieve the presented information processing was developed. The effectiveness of this system was used and validated at the municipality. This study was conducted as part of the Special Project for Earthquake Disaster Mitigation in Urban Areas that the Ministry of Education, Culture, Sports, Science and Technology of Japan.

### APPLICATION OF EARTHQUAKE DESTRUCTIVE INDEX CONSIDERING THE NUMBER OF EARTHQUAKE RESPONSE CYCLES – ID 773

*A. Murata, Kanazawa University, Japan*
*M. Kitaura, Kanazawa University, Japan*
*M. Miyajima, Kanazawa University, Japan*

In general, peak ground acceleration (PGA), peak ground velocity (PGV), seismic intensity and spectral intensity (SI) have been used as the indices of destructive power on earthquake motion. However, it is quite important to consider the number of earthquake response cycles in the vicinity of the maximum response and natural period of structures for predicting damage to structures. Especially, destruction of the wooden structure was expanded by aftershock after the main shock in 2004 Niigata-ken Chuetsu earthquake. In this study, the influence by accumulation of the earthquake motion on wooden structure destruction is considered. The fatigue response spectral intensity (FSI) of having taken the repetition of earthquake motion into consideration is applied, and a relation with wooden structure damage is considered. This index, which is called as FSI, is defined as integrated value on tripartite coordinates: natural period of wooden structures, pseudo-response velocity spectra and number of seismic response cycles. FSI was calculated by using the response to recent earthquakes in Japan such as the 2004 Niigata-ken Chuetsu Earthquake and so on. As a result, it was clarified that accumulation of an earthquake motion influences structure damage and the earthquake motion destructive power index proposed by this research that accumulation of the earthquake motion by aftershock can be taken into consideration is effective. Based on this study it is concluded that FSI value demonstrate the damage ratio more accurately than alternative indices such as seismic intensity, PGV, and SI value.

### PROGNOSIS OF DAMAGE FROM STRONG EARTHQUAKES ON THE BASE OF RELATIONS BETWEEN EARTHQUAKE PARAMETER – ID 1040

*M. Rodkin, Geophysical Center RAS, Russian Federation*
*V. Pisarenko, International institute of the theory of the progn, Russian Federation*
*A. Gvishiani, Geophysical Center RAS, Russian Federation*

Rather frequently the magnitude of damage from earthquake became known essentially later than the disaster occurs that causes some disparity in the rescue operations and in rendering of international humanitarian assistance. For timely actions the information about expected number of casualties and loss value is critical. The well known method of scenarios of disaster is known to present the proper information in near real time regime. But this method crucially depends on the large volume of information about local housing of the damaged region that should be collected and pre-examined well before the occurrence of disaster. Such detailed information in many cases can be absent. In these cases the simpler approach can be used. This approach is based on a number of empiric relations that were revealed between the geophysical parameters of disasters and the regional annual per capita income and density of population. These estimates appear to be more precise for large disasters because of the effect of averaging. The accuracy of the method can be increased if the current social and economic information is taken into account. Such information is particularly important if the economic and social situation changes rapidly. Besides, in order to improve the quality of information on the population density in the epicentre of disaster the current night lights database can be used. Examples of the use of the presented approach are discussed.

### SCENARIO EARTHQUAKE CONSEQUENCES AND SEISMIC RISK MAPPING: CASE STUDY FOR THE NORTHERN CAUCASUS – ID 1266

*N. Frolova, Seismological Center of IGE, RAS, Russian Federation*
*V. Larionov, Extreme Situations Research Center, Russian Federation*
*J. Bonnin, Institute of Physics of the Earth, France*
*E. Rogozhin, Institute of Physics of the Earth, Russian Federation*
*O. Starovojt, Geophysical Survey, RAS, Russian Federation*
*L. Chepkunas, Geophysical Survey, RAS, Russian Federation*

The paper addresses methodological issues for expected damage and loss estimation due to strong earthquakes, as well as individual seismic risk assessment and mapping with GIS-technology application. The principle procedures for estimating seismic hazard, vulnerability of elements at risk and impact on population are presented in «The Methods of Earthquake Consequences Assessment» developed by Extreme Situations Research Center, Seismological Center of IGE, Russian Academy of Sciences and other organizations, which was approved by the Russian Interdepartmental Coordination Scientific Council on Civil Defense and Emergency Problems in 2000. The probabilistic approach is used in "The Methods" for forecasting possible strong earthquake consequences and values of seismic individual risk. "The Methods" allows to determine the number of fatalities and injuries due to strong event, number of homeless people in the stricken area, number of buildings and structures of different types according to MMSK-86, which survived different damage states. The debris volume and its characteristics, number of sites where buildings and structures should be strengthen or demolished and other auxiliary indexes may be estimated with the procedure application.

The paper is providing the results of scenario earthquakes consequences due events which may occur in the most hazardous possible source zones in the Northern Caucasus. The expected social losses due to different scenario events proved to be rather high, but taking into account the reoccurrence period T=1500-2000 years, the probability of such events is relatively low.

The estimations of individual seismic risk for the Northern Caucasus territory was fulfilled with taking into account direct damage to buildings and with taking into account secondary technological accidents. The obtained values of risk varies from negligible ones up to rather high values equal to 40.0•10 -5, 1/year. For more than 30% of the considered territory the individual seismic risk exceeds the value equal to 1.0•10-5, 1/year.

### QUANTITATIVE ASSESSMENT OF SEISMIC RISK IN BISHKEK CITY, KYRGYZSTAN – ID 1557

*K. Murataly, Seismology, Kyrgyzstan*
*K. Yrysmendi, Seismology, Kyrgyzstan*

The results of the strong earthquake investigations in large countries of the world of the last years was showed that the number of victims between the population and the scale of material damage would be more less, if the seismic risk of populated territories will be valued in time, i.e. to realize the plan of seismic risk of management, that means the strengthening of existed constructions and elaborating of new constructions and technology of building of earthquake-resistant buildings. As the basic theory had been accepted the US Geologic Service methodology. The consequences of seismic risks are presenting of the strong earthquakes observed dramatic effect on local site conditions. For example: obvious differs of the same style buildings‘ conditions, which are situated on the ground with the different site conditions. For the definition of buildings‘ seismic damages had been used the program of KOERILoss, which is based on GIS technology. With the help of given program software were got the curved vulnerabilities for all of the types of buildings in Bishkek city. These curves show the cumulative damage variety of apartment houses according to the spectral displacements by the four damage rates: slight, moderate, extensive, complete. For the evaluation of possible damages had been used the vulnerability matrixes, which describes the dependence between the intensity of seismic vibrations and the damage levels of buildings. Probabilistic matrixes‘ vulnerabilities have done for all types of buildings. There were checked the possible damages for Bishkek city apartment houses, which based on the spectral displacement method. As the result have got the maps of damage level for all of the types of the buildings with 2% and 10% probabilistic exceedance in 50 years.

## SS 1: Tsunamis in the European Mediterranean Region and the Sumatra Earthquake and Tsunami in the Indian Ocean
Level 2

### MODEL TESTING OF TSUNAMI SAFE(R) HOUSE DESIGN – ID 1526

*T. Indrasenan, University of Cambridge, UK*
*M. Gopal, University of Cambridge, UK*

Asian tsunami of December 25th 2005 claimed more than 220 000 lives and made 800 000 people homeless. The total economic cost of catastrophe is estimated to be more than 10 billion euros. While a tsunami waning system is essential for evacuation of people from costal areas, better designs for costal houses can improve their chances of survival in an event of a tsunami and reduce the economic and financial loss to the costal community.

This paper presents results of model testing of tsunami safe(r) house design by Tsunami Design Initiative, a student initiative at Harvard Design School, in collaboration with Massachusetts Institute of Technology (MIT). The new house design has four core columns instead of four solid walls as in convectional designs, thus provides less resistance for the passage of the wave. Walls of wood or bamboo are built in between the columns. A scale model (1/25th) of the prototype new design was tested in a large wave tank in which a tsunami wave was created. A scale model of a typical costal Sri lankan house was also tested to show the tsunami wave induced damage to such houses. The tsunami wave was created by dropping a heavy weight ( 100 kg) into the water at the deepest end of the tank. The sudden displacement of water in the deep end of the tank creates the wave and the wave propagates to the shore where the model house was placed. A high speed (1000 frames/s) video camera was used to capture the tsunami wave as it hits and propagates pass model building.

The results from model scale testing showed that the new design performed well under the wave loading. The tsunami wave passed through the structure without causing any major damage.

### SIMULATED STRONG GROUND MOTIONS FOR THE GREAT M9.3 SUMATRA-ANDAMAN EARTHQUAKE OF DECEMBER 26, 2004 – ID 1963

*M. B. Sørensen, University of Bergen, Norway*
*K. Atakan, University of Bergen, Norway*
*N. Pulido, NIED, Japan*

On December 26, 2004, a devastating earthquake of M=9.3 occurred offshore Northern Sumatra. Due to the size of this earthquake and the accompanying tsunami wave, disastrous consequences have been observed in several countries around the Indian Ocean. The tectonics in the region are characterized by the oblique, NNE oriented subduction of the Indian-Australian plate under the Sunda microplate with a rate of 6-6.5 cm/yr. This oblique convergence results in strain partitioning, where the trench perpendicular thrust faulting along the subducting slab accommodates the E-W component of the motion, whereas the N-S component of the motion is probably accommodated by the right-lateral strike slip faulting along the Great Sumatran Fault and the Mentawi fault. Source parameters of the December 26, 2004 event have been used for modeling the resulting ground motions in the nearby affected regions. Results give an insight on the importance of ground shaking in the total destruction of places like Banda Aceh, Northern Sumatra, Indonesia. The

modeling is performed for a multi-asperity finite fault using a hybrid procedure combining deterministic modeling at low frequencies and semi-stochastic modeling at high frequencies. Results show that strong shaking was distributed over a large area including northwestern Sumatra and its off-shore islands. In Banda Aceh, which experienced significant damage, bedrock velocities reached 60 cm/s with duration of the shaking of ca 150 s. The largest ground motions occurred near the strongest asperities of the fault plane, where velocities of 200 cm/s are modeled for bedrock conditions.

### THE STRESS FIELD OF THE SUNDA ARC SUBDUCTION ZONE INFERRED FROM EARTHQUAKE FOCAL MECHANISMS INCLUDING THE MAIN- AND AFTERSHOCKS OF THE DECEMBER 26TH 2004 NORTHERN SUMATRA EARTHQUAKE – ID 2046

*T. Plenefisch, SZGRF/BGR, Germany*
*K. Klinge, SZGRF/BGR, Germany*

We use earthquake focal mechanisms to investigate the stress field of the Sunda Arc subduction zone. The final scope of our investigations is to get a three dimensional image of the stress field by resolving possible lateral changes along the arc as well as depth dependent changes. To study the stress field we use moment tensor solutions of the Harvard moment tensor catalogue and apply the inversion method by Gephart & Forsyth (1984). Our dataset consists of 964 moment tensors with magnitudes between Mw = 4.6 to 8.3 from the time period 1977 – 2003 which cover the Java and Sumatra region. On the occasion of the recent magnitude 9 Northern Sumatra event of 26 December 2004 we extended our data by its moment tensor and 702 stronger aftershocks which cover the region of NW Sumatra, Andaman and Nicobar Islands. Up to now, the following results can be inferred from the inversions: 1. Below Java there is a change in the orientation of the maximum principal stress axis S1 from subhorizontal in the shallow parts (0 – 200 km depth) to subvertical in the depth range of 400 – 670 km and vice versa for S3. This result is in agreement with stress and strain conditions found in other subduction zones of the world which show down-dip extension in the upper part (0 – 300 km) of the subducting plate and down-dip compression in the lower part (400 – 700 km) (e.g. Apperson & Frohlich, 1987). 2. The region of NW Sumatra, the Andaman and Nicobar Islands shows a N-S to NNE-SSW orientation of the S1-axis, which is in agreement with the NNE directed subduction of the Indian plate underneath the Burma microplate.

## SS 2: Earthquake Loss Modelling : From Earth Sciences to Insurance Applications

Level-1

### AN EARTHQUAKE LOSS EVALUATION MODEL TO FACILITATE THE SUITABLE RISK-BASED LAND USE DECISIONS AND POLICIES WITH HAZARD INSURANCE – ID 108

*A. Taylan, Middle East Technical University, Turkey*

This presentation focuses on some hazard and vulnerability elements that are necessary for developing an earthquake loss evaluation model in urban areas to be used in the context of an urban risk management model, which aims to facilitate hazard insurance as an instrument to implement the risk based plan decisions. Through evaluation of earthquake losses in urban residential areas, suitable land-use plan decisions can be developed to reduce the earthquake risk and create more resilient societies. The model aims to envisage an urban risk inventory with the hazard and vulnerability elements through the findings of both engineering studies such as geological, geophysical and civil engineering, and social, psychological and economic studies in a holistic framework. This inventory will be beneficial for urban planners and local managers, on one side, and for the obligatory earthquake insurance (OEI) mechanism in Turkey, on the other side. Each scale of planning decision such as macro (country), mezo (metropolitan) and micro (districts of metropolitans and medium or small sized cities), may benefit from it identify, avoid and reduce the risks. On the other side, this inventory can be beneficial for the identification of risks by the OEI mechanism to decrease the uncertainty of risk, so that to overcome the information asymmetry problems like adverse selection and moral hazard, which are faced by the natural hazard insurance systems. Besides, OEI can envisage tariffs, coinsurance and deductibles, which may, in turn, contribute to the urban risk reduction strategies as financial incentives that may be effective instruments to implement land-use plan decisions with cooperation of central and local governments. This may provide, in turn, the OEI to increase the penetration ratio in the pool and solve the insolvency problem.

### CRUSTAL STRESS, SEISMIC HAZARD, ACOUSTIC EMISSION AND INSURANCE – ID 176

*A. Zanini, University of Rome "Tor Vergata", Italy*
*G. P. Gregori, International Centre for Earth Sciences, Italy*
*G. Paparp, Institute of Acoustic "O.M. Corbino", C.N.R., Italy*
*M. Poscolieri, Institute of Acoustic "O.M. Corbino", C.N.R., Italy*

The timing of a forthcoming earthquake can be approximately and significantly predicted, within some given large area, by means of suitable records of ultrasounds (acoustic emission, AE), collected at one location alone. Concerning the Italian peninsula, a paroxysm is observed with an advance of 7-8 months by means of AE at 200 kHz, and with an advance of 2 months by means of AE at 25 kHz. It is reasonable to expect that shorter time advances can be attained by means of AE at some lower frequencies. Analogous, though in principle different, time patterns are to be observed in other tectonic environments. One such case history is e.g. the Chephallonia area in Greece. Such information appears well suited for a reasonably accurate temporal forecast, although with no actual capability of predicting the epicentral area. An information about the expected location of a forthcoming earthquake can be achieved by means of other methods. The classical seismic gap can give, whenever applicable, a reasonably accurate epicentre location. The fractal analysis of the space distribution of faults, derived from standard neotectonic maps, seems to be suited for predicting the maximum magnitude to be expected to occur within every given area. Such entire set of information seems unlikely to permit any accurate prevision of earthquakes. It appears however reasonable expecting that such multi-facet approach can provide with significant statistical information on the expected damages and hazard.

### OPERATIVE EARTHQUAKE PREDICTION FOR INSURANCE – ID 433

*V. Sibgatulin, KNIIGiMS, Russian Federation*
*K. Simonov, ICM SB RAS, Russian Federation*
*S. Peretokin, KNIIGiMS, Russian Federation*

The research deals with a problem of control over a preparation process of a severe earthquake and its express diagnostics so as to tackle a problem of providing efficient prediction. The technique of analyzing earthquake preparation process is based on studying the energy structure of a focal area under control and plotting energy levels of the studied process according to the seismic monitoring data. Eliciting certain energy precursors and inspecting their alterations enables one to provide a dynamic (adaptive) prediction of temporal and magnitude characteristics of an expected seismic event in accordance with the data received. This technique has been tested on different seismic areas and well-studied earthquakes that occurred over the last few years and shown good prognostic qualities. The research provides the results of the practical implementation of the aforesaid technique by KNIIGiMS seismological service. In the year of 2005 using the data of the global and regional seismic monitoring systems we carried out express diagnostics of the preparation process of severe earthquakes that cost great sacrifices in blood and treasure. Thus,

we carried out a methodologically consistent contrastive analysis, found characteristic features of the preparation and aftershock processes of the largest earthquakes of 2005 that occurred in different seismic areas. It is shown that the energy precursors elicited in the real-time mode provide an essential contrast and lead time for practical use by the services of natural hazard mitigation. The developed technique of operative earthquake prediction is intended to tackle certain problems concerning insurance.

### MONETARY EARTHQUAKE RISK DISCUSSION OF THE MODELLING; THE COMPARABILITY AND FACTORS OF INFLUENCE – ID 455

*M. Raschke, Co. M. Raschke, Germany*

In the science community of seismologists and earthquake engineers, the risk of earthquake damages is almost exclusively described by an earthquake scenario. This approach is called "simple earthquake risk analysis" in this work. In contrast, there are models and software programs in the insurance and reinsurance sector which determine the mean frequency of earthquake events in relation to their cumulated monetary damages. However, frequently, the basic principles of these models of this "complete earthquake risk analysis" are not accessible and not discussed in the science community. In this paper, the complete earthquake risk analysis, i.e. the calculation of the mean frequency of the cumulated monetary building damages of each earthquake, is discussed and compared to the approaches of the hazard analysis. Since the hazard model is an important component of any risk analysis an extensive and clear comparison of different hazard models is carried out – the mean of the frequency functions of the local earthquake shacking of all places in the region concerned. Further, both the modelling and the influence of the attenuation relation, the maximum quake (Mmax, Io max) and the damage functions are presented and discussed. The modelling of the influences of the amplification or attenuation of the local earthquake shacking (Sa(T), amax, I) of a site on the damage functions is also discussed. Finally, the demand for research in earthquake science is formulated from the perspective of risk analysis.

### EMS-98 AS A TOOL FOR LOSS ESTIMATION – ID 554

*R. M. Musson, BGS, UK*

For the purpose of estimating earthquake loss to a large assemblage of buildings (as opposed to a single building), approaches using physical parameters of earthquake ground motion are affected by the quality of the correlation between strong ground motion and damage. In addition, expected ground motion from a future earthquake at a site is subject to lognormal scatter. A robust alternative is to use intensity in place of physical ground motion parameters. An intensity attenuation equation is essentially a numerical description of the probability of damage to buildings as a function of distance and magnitude, derived directly from past observations of damage. Furthermore, intensity data are more copious for many parts of the world than are strong ground motion records, so locally validated intensity attenuation equations are more easily found than those for peak ground acceleration or velocity. EMS-98 is particularly appropriate for this type of use because of its probabilistic basis; each degree of the scale can be represented by the expected distribution of damage grades to buildings of different vulnerabilities. Implementing a simulation-based approach to loss estimation provides a straightforward way to estimate general expected loss levels to large assemblages of normal domestic buildings. The main limitation is that losses to special structures such as bridges, skyscrapers or industrial plant cannot really be obtained in this way.

### STRUCTURAL CHARACTERISATION OF TURKISH R/C BUILDING STOCK FOR LOSS ASSESSMENT APPLICATIONS – ID 603

*I. E. Bal, ROSE School, Italy*
*H. Crowley, EUCENTRE, Italy*
*R. Pinho, EUCENTRE, Italy*
*F. G. Gulay, Istanbul Technical University, Turkey*

Assessing earthquake vulnerability of building stock in the earthquake-prone Marmara region of Turkey is of growing importance, since such information is needed for reliable estimation of the losses that future earthquakes are likely to induce. The outcome of such loss assessment exercises are used in planning of urban/regional-scale earthquake protection strategies; a priority in Turkey, particularly following the destructive earthquakes of 1999. Considering the size of the building inventory Istanbul and surrounding area is a case which is not easy to determine its properties and characteristics. In this paper, geometrical, functional and material properties of building stock in northern Marmara region, particularly around Istanbul, have been investigated and evaluated for further loss estimation models and other types of statistic or probability based studies. In order to do that, the existing stock has been classified as new and old buildings, dual frame or frame structures, and emergent or embedded beam systems. Additionally to statistical parameters such as mean values, standard deviations etc., probability density functions (PDF) and their goodness-of-fit cases have also been investigated for all types of parameters. Correlations between structural parameters have been checked whether they have physical meaning or not. Functionalities such as purpose of use, floor area properties have been defined. Concrete properties of existing and recently constructed buildings and also characteristics of 220 MPa and 420 MPa types of steel have been documented. Finally, structural and financial effects of retrofitting operations have been demonstrated.

### GROUND MOTIONS AND CASUALTIES IN THE 1999 CHI-CHI, TAIWAN EARTHQUAKE – ID 703

*M. Sullivan, Risk Management Solutions, Inc., United States*
*T. Onur, Risk Management Solutions, Inc., United States*

Understanding the drivers of earthquake morbidity and mortality is crucial in loss estimation and in earthquake planning and response. Although there is extensive research evaluating quantitative relationships between strong motion characteristics and building response, relatively fewer studies provide correlations between casualties (especially injuries) and various earthquake parameters. This is mainly due to the shortage of good quality data on earthquake-related casualties in large events. The large strong-motion network in Taiwan and quality of the casualty data gathered after the 1999 Chi-Chi earthquake creates a unique dataset from which to begin to quantify the relationship between ground-motion parameters and casualties.

In this study, we focus on several ground motion parameters that are commonly in use in seismology and earthquake engineering to represent ground shaking intensity, and test their correlations with injuries and fatalities. The parameters we consider here are Modified Mercalli Intensity (MMI), peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (SA) at periods of 0.2 sec, 0.5 sec, 1.0 sec, and 2.0 sec. The correlations are examined at two geographic scales, village level and township level, in order to investigate the effect of aggregation methodology and resolution. We also investigate whether the parameters that show better correlation with casualties can be explained by the dynamic response characteristics of the more prevalent building types in the region.

### A METHOD TO EVALUATE THE MACROECONOMIC DISASTER DEFICIT – ID 710

*O. D. Cardona, Universidad Nacional de Colombia, Colombia*
*M. Ordaz, Universidad Nacional Autónoma de México, Mexico*
*A. M. Moreno, Universidad Nacional de Colombia, Colombia*
*S. Santa-Cruz, Universidad Nacional Autónoma de México, Mexico*

The Disaster Deficit Index (DDI) is an indicator that measures country risk from a macroeconomic and financial perspective according to possible catastrophic events. The DDI captures the relationship between the demand for contingent resources to cover the losses caused by a Maximum Considered Event and

the public sector's economic resilience; that is, the availability of internal and external funds for restoring affected inventories. For calculating potential losses the model follows the insurance industry in establishing a probable loss, based on the critical impacts during a given period of exposure, and for the economic resilience the model computes the country's financial ability to cope with the situation taking into account: the insurance and reassurance payments the country would approximately receive for goods and infrastructure insured by government; the reserve funds for disasters that the country has available during the evaluation year; the funds that may be received as aid and donations, national or international; the possible value of new taxes the country could collect in case of disasters; the margin for budgetary reallocations of the country, which usually corresponds to the margin of discretional expenses available to government; the feasible value of external credit that the country could obtain from multilateral organisms or from the capital market; and the internal credit the country may obtain from commercial and the Central Bank. Access to these resources has limitations and costs that must be taken into account as feasible values according to the macroeconomic and financial conditions of the country. This paper presents the model of DDI and the results for twelve countries of the Americas in the framework of the Program of Indicators for Disaster Risk Management, which was developed with the support of the Inter-American Development Bank (IDB) to design appropriate risk evaluation tools to guide the governmental decisionmaking.

### SEISMOCARE: AN EFFICIENT GIS TOOL FOR SCENARIO-TYPE INVESTIGATIONS OF SEISMIC RISK OF EXISTING CITIES – ID 769

*S. Anagnostopoulos, University of Patras, Greece*
*C. Providakis, Technical University of Crete, Greece*
*P. Salvaneschi, ISMES-ENEL, Italy*
*G. Bonacina, ISMES-ENEL, Italy*

The need for efficient and reliable estimates of the socio-economic impacts of large earthquakes in existing cities has been clearly demonstrated with recent earthquake events experienced around in the world. Such estimates can be quite useful for pre disaster planning and for implementing seismic risk mitigation policies. They can be done through scenario type studies, which are based on the available seismotectonic information and on a detailed inventory of the elements at risk in the area under consideration. A geographical information system (GIS) is an ideal tool for carrying out such scenario type earthquake damage and loss estimations. The work presented herein was performed as part of a three year project, the 1998-2001 SEISMOCARE project, supported by the European Community and involving collaborations of five partners: the Universities of Patras and Rome, the Technical University of Crete in Chania, EQE International in London and ISMES in Bergamo. The objective of the project was to develop an integrated GIS methodology and to produce a software package for reliable prediction of losses due to earthquakes in a city or region. The developed software is essentially a simulator that for any scenario type earthquake can provide loss estimates for the affected area, in terms of expected casualties, building damage, utility interruptions, economic losses etc. The innovation of the project is not in the development of new methods for carrying out its various phases, but rather in the extensive utilization and integration of state-of-the-art information processing tools for hazard, vulnerability and risk assessments that will yield more reliable and easier to use loss estimates. The simulator was tested by applying it to the Greek city of Chania, in the island of Crete, and the results obtained were used for calibrating the methodologies and techniques implemented in the SEISMOCARE simulator.

### A GENERALIZATION OF FRAGILITY BASED ON SEISMIC CAPACITY INDEX – ID 868

*I. Sato, Tokio Marine & Nichido Risk Consulting Co., Lt, Japan*
*H. Yashiro, Tokio Marine & Nichido Risk Consulting Co., Lt, Japan*
*K. Ohta, Tokyo Electric Power Services Co., Ltd., Japan*
*S. Fukushima, Tokyo Electric Power Services Co., Ltd., Japan*

For the adequate damage estimation in the earthquake risk management business, it is required to quantify the seismic vulnerability of the facilities, which is given in the form of fragility curve. Though a lot of fragilities based on the damage records in Kobe earthquake are proposed, they are not suitable from the viewpoint of the risk management, since they can give us only limited damage state such as "collapse". This study aims to generate fragility of any buildings corresponding to any damage state. This study consists of two stages; the first one is to obtain general expressions by regression analysis for the varieties of buildings using Monte Carlo simulation, and the second one is to calculate the seismic loss function of model buildings as trial case. We found that the proposed method is very useful for practical risk management since fragility for any damage state defined by inter-drift angle can be applied to any drift-sensitive non-structural component as well as structure.

### PROBABILISTIC VULNERABILITY ANALYSIS: AN APPLICATION TO TYPICAL SCHOOL BUILDINGS IN ISTANBUL – ID 889

*U. Hancilar, Kandilli Observatory and Earthquake Research Inst., Turkey*
*E. Durukal, Kandilli Observatory and Earthquake Research Inst., Turkey*
*G. Deodatis, Columbia University, United States*
*G. Franco, Columbia University, United States*
*M. Erdik, Kandilli Observatory and Earthquake Research Inst., Turkey*
*A. Smyth, Columbia University, United States*

In this study, probabilistic structural vulnerability analysis of a typical school building in Istanbul is performed. A three-dimensional numerical model of the structure is created for comparison and verification purposes both by SAP2000 (Static and Dynamic Finite Element Analysis of Structures) and OpenSees (Open System for Earthquake Engineering Simulation) computer codes. A linear-elastic modeling and analysis procedure is followed in SAP2000 and used for the verification of the model created using OpenSees. The inelastic dynamic behaviour of the structure is modelled in OpenSees environment. The nonlinear time-history analyses under simulated strong ground motion time histories compatible with regional earthquake hazard are conducted. First, the structural dynamic analyses are performed for a fully deterministic structural model based on the blueprints of the typical project. Uncertainties in material properties (e.g. compressive strength of concrete, yield strength of reinforcing steel), structural characteristics (e.g. plan geometry, cross sectional dimensions of beams, columns and shear walls) and input ground motion (particularly the earthquake source, phase properties and angle of incidence) are accounted for by applying a modified version of the algorithm used in Smyth et al.(2004) which considers the random variation of aforementioned parameters with a set of N experiments based on a Monte Carlo approach. The random variation of these parameters is constrained by their statistical distributions obtained from in-situ measurements and material sampling tests. The structure automatically generated with random material properties and element characteristics is subjected to earthquake motions in random directions, which are simulated using a hybrid approach and consider the variation in ground motion properties due to earthquake source, path and site effects. The peak inter-storey drifts are computed as a measure of nonlinear structural response. The fragility curves, probability of exceeding damage versus PGA, are presented for different damage levels.

### SEISMIC INDIRECT LOSS MODEL FOR INDUSTRIAL FACILITIES – ID 1076

*K. Nasserasadi, IIEES, Iran (Islamic Republic Of)*
*R. Mechler, IIASA, Austria*
*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*

Indirect economic impacts of earthquake which is known as business interruption is produced as a result of disruption in

the flow of good and services due to direct physical damages to stocks or lifelines. It has been observed that the recover time is significantly contributed in the indirect losses. Existing models for estimation of recovery time of facilities has been mostly developed by expert opinion. In this paper, an analytical model for estimation of earthquake induced indirect economic impacts of industrial facilities based on system dynamic approaches is introduced.

In the proposed model, system dynamic approach is employed for estimation of recovery time of factory after a probable earthquake by estimation of reconstruction time and recovery time after reconstruction. In this method, first a conceptual recovery framework for recovery of industry after earthquake has been developed by considering contributing factors on recovery level like availability of financial resource for reconstruction, lifeline, households, availability of source for production and demands. Then a simulation technique is employed for developing the numerical platform of the model and the method is applied to a hypothetical refinery and the results are presented in addition to some parametric studies. The numerical results have shown that the degree of indirect losses is significantly higher than direct one in the numerical example.

### MODELLING SEISMIC RISK IN SWITZERLAND – ID 1202

*T. Lai, AIR Worldwide Corporation, United States*
*K. Shabestari, AIR Worldwide Corporation, United States*
*J. Guin, AIR Worldwide Corporation, United States*
*P. Towashiraporn, AIR Worldwide Corporation, United States*

Earthquake hazard in Switzerland is low relative to regions of Southern Europe and the Mediterranean. Yet the region has experienced damaging earthquakes, such as the 1356 Basel and 1855 Visp earthquakes. In this, the 650th anniversary year of the 1356 Basel earthquake, government and private researchers are reassessing seismic risk in Switzerland in light of both the low probability threat and the less seismic resistant building inventory. As part of this effort, the authors have developed a probabilistic earthquake loss-estimation model for Switzerland to facilitate the management of catastrophe risk by the (re)insurance industry. The model includes ground motion estimation and building vulnerability modules, as well as an industry-wide building inventory database that categorizes structures by wall material and building height. This paper presents technical details on the ground motion hazard and building vulnerability. Ground motions are calculated based on Bay et al. (2003) and Ambraseys et al. (1996) attenuation relations, which is then adjusted through the NEHRP (National Earthquake Hazard Reduction Program) soil-amplification procedure according to surface geology. Building vulnerability is measured as a function of Roof Drift Ratio (RDR), which is estimated through the Capacity Spectrum Method (CSM). For masonry construction which is a dominant type in Switzerland, the capacity curve is developed based on experimental and/or analytical studies of buildings specific to the Swiss practice. The model is used to estimate loss distributions of selected historical events, were these events to recur today. The loss distributions reflect the uncertainty in the source parameters of these events as estimated from pre-instrumental era. The selected events include the 1356 Basel and the 1855 Visp earthquakes.

### EARTHQUAKE DAMAGE AND LOSS ESTIMATION ON A REGIONAL SCALE – ID 1422

*S. Tyagunov, University of Karlsruhe, Germany*
*G. Grünthal, GeoForschungsZentrum, Germany*
*R. Wahlström, GeoForschungsZentrum, Germany*
*L. Stempniewski, University of Karlsruhe, Germany*
*J. Zschau, GeoForschungsZentrum, Germany*

The main goal of earthquake damage and loss estimation studies is to provide information and support for the decision-making process to guide cost-effective risk management policy in earthquake-prone regions taking into account their specific needs and existing circumstances. The necessary information should include, on the one hand, spatial distribution of existing risk in the area under study and, on the other hand, the level of damage and losses from probable future earthquakes. The paper presents a methodology of damage and loss analysis, which is developed in the frame of an interdisciplinary project "Risk Map Germany" conducted by the Center for Disaster Management and Risk Reduction Technology – CEDIM. The conceptual framework of the GIS-based methodology follows the traditional pattern and includes analysis of probable seismic influence, structural vulnerability of the built environment and exposed assets in communities of the country. For analyses of damage and losses both hazard-based and scenario-based approaches are used in the study. The former provides the possibility of comparative analysis of risk distribution in the whole country for identification of most endangered communities. The latter offers the possibility of estimation of the level of probable damage and losses from potential single seismic events. The results obtained with the use of the hazard-based approach are presented as maps of the probable seismic damage and seismic risk distributions. In parallel, the scenario-approach is applied for a few selected earthquake-prone communities of the country. The results are calibrated with the observations from several damaging earthquakes in Germany and the nearby area in the past 30 years.

### RISKSCAPE (NZ) - A MULTIHAZARD RISK ASSESSMENT PROGRAMME – ID 1501

*A. King, GNS Science, New Zealand*

New Zealand has long been recognized as having a high exposure to earthquake related hazards. In fact New Zealand has the dubious privilege of being exposed to nearly all natural hazards and in many cases this exposure is recognized as being "high" to "severe" by international standards. While considerable advances have been made over the past few decades in understanding the mechanics that underpin these phenomena, only recently has sufficient knowledge been acquired to enable some rational probabilistic models to be developed to quantify the intensity/recurrence relationships of these hazards. By establishing fragility functions for all items of community inventory to the actions resulting from each of these natural phenomena, community risk and thence probable losses can now be ascertained, albeit with varying degrees of reliability.

This paper discusses the development of RiskScape New Zealand, a national multi-hazard impact model that will be able to ascertain relative risks and community exposure to a range of natural hazards. The prototype currently under development and will include earthquake, tsunami and volcanic exposure together with flood and storm impact. Three representative New Zealand communities will be used in the pilot with the default inventory database including buildings, infrastructure, public utility and transportation networks.

The challenge of presenting date derived using either the probabilistic or scenario approach proposed to an essentially non-technical user group and getting their uptake remains before us but will be discussed in the paper along with progress to date.

### CONSEQUENCE ASSESSMENT OF EARTHQUAKES: BAM CASE STUDY – ID 1597

*M. Faizian, IBB, ETHZ Zürich Switzerland, Switzerland*
*H. R. Schalcher, IBB, ETHZ Zürich Switzerland, Switzerland*

The present paper reports on the methodical developments in regard to the modelling and assessment of consequences due to earthquakes within a multidisciplinary research project presently performed at the Swiss Federal Institute of Technology. The research project aims to develop a generic decision theoretical framework for the consistent quantitative and rational management of earthquake risks in three situations, namely before, during and after an earthquake. First the general framework for the earthquake risk management project is outlined. Thereafter the specific issues relating to the modelling of consequences of earthquakes are addressed including a review of existing methodologies and results of research projects reported in the literature. Finally an example of a Bayesian Probabilistic Net model considered in the project for consequence analysis is presented and it is explained how the net may be utilized for assessing the consequences of relevance prior, during and after an earthquake.

### BUILD ENVIRONMENT AND SEISMIC RISK ASSESSMENT IN TBILISI – ID 1628

*I. Timchenko, ISMEE, Georgia*
*G. Lomidze, AGESAS, Georgia*

Essential characteristics of the building stock of Tbilisi influencing on the seismic risk and their analysis are presented. High-risk groups of buildings are emphasized; their behavior at the 2002 epicentral earthquake is described. Based on the main characteristics of the building stock the technique of seismic risk calculation is presented. It includes classification of buildings by structural type, selection of vulnerability curves, compilation of data base of the building stock, development of software for risk computation. A set of modifiers participate in risk assessment, representing influence of soil conditions, resonance phenomena, regularity, topography, technical conditions and other are implemented and discussed. The technique of seismic risk assessment has been tested in the selected district of the city including almost all representative types of buildings. The developed software allowed to define and evaluate the most important factors (modifiers) influencing seismic risk – technical conditions, presence of damages in buildings due to settlements and previous earthquakes, influence of soil conditions. On the basis of calculations a set of maps of risk in replacement values and damage grade for cases of different level of seismic excitation have been compiled. Maps of annual risk for purposes of insurance have been compiled, the importance of earthquake insurance as an effective tool for risk mitigation is shown and discussed. The work has been performed within NATO SfP Project "Seismic Risk in Large Cities of Caucasus. Tools for Risk Management".

### VULNERABILITY FUNCTIONS AND DAMAGE PROBABILITY MATRICES FOR UK BUILDING STOCK – ID 1662

*A. J. Weston, University of East Anglia, UK*
*P. Burton, University of East Anglia, UK*

The emphasis of this paper is on the development of earthquake vulnerability functions and damage probability matrices (DPMs) for typical UK buildings. This work forms part of an overall earthquake impact scenario of the area surrounding the Colchester earthquake of 1884, one of the UK's most damaging earthquakes to date.

Maps of forecasted intensities modelling seismic hazard have been produced, using Kovesligethy's attenuation relationship fitted to damaging near-field 1884 macroseismic data and a newly developed local soil amplification scheme. The built environment has been analysed using fieldwork, aerial imagery and additional data sources. 93,320 buildings have been analysed - 98.5 % are masonry and 1.5 % non-masonry (reinforced concrete, steel frame and historic timber frame). Damage probability matrices and vulnerability curves have been developed for six vulnerability types linked to the building stock, using vulnerability functions derived from worldwide damage surveys.

Seismic risk results for the repeat 1884 scenario show that 35 - 46 % of the building stock within a study area of 625 km2 would be expected to suffer damage distributed across the five damage grades (D1 to D5, MSK-81 and EMS-98) as follows: 20 - 25 % D1 (negligible to slight damage); 9 - 11 % D2 (moderate damage); 5 - 6 % D3 (substantial to heavy damage); 1 - 3 % D4 (very heavy damage); and 0 - 1 % D5 (near total collapse). Damage costs for this repeat 1884 scenario are estimated at 6.1 to 9.9 % of the total building construction cost, which translates to approximately £731 to £1,180 million (at modern values). These results lead to an important finding: that although the media might emphasise the striking devastation at D5, even D1 losses are financially significant and the bulk of losses are at D3. This is of concern to the insurance and reinsurance industry in the wider context of the total costs arising from damaging earthquakes.

### SEISMIC HAZARD AND ECONOMICS FOR AN OIL FACILITY IN SOUTHERN MEXICO – ID 1805

*M. Chavez, ENS, France*
*P. L. Velasco, PEMEX, Mexico*
*E. Cabrera, UNAM, Mexico*
*N. Perea, UNAM, Mexico*

The seismic potential of southern Mexico, where the Isthmus of Tehuantepec (IT) is located has been demonstrated over the last centuries (García-Acosta, Suarez, 1996). In this region, the Cocos, North American and Caribbean tectonic plates interact, and as a result of the latter, the occurrence of Subduction Superficial (SS), Subduction Deep (SD), and Crustal Superficial (CS) earthquakes takes place. Historically, the largest Richter magnitudes, Ms, for the SS, SD, and CS observed in the region are 8, 7.2 and 6.5, respectively. In this work, by applying a hybrid method (successfully tested, to obtain synthetics of the strong ground motions observed for the 09/10/1995 Colima-Jalisco Mw 8, SS event, Chavez et al., 2004, 13thWCEE) we generated sets of broadband synthetic accelerograms, expected in the surficial soils of an oil facility site located in the north of the IT, for extreme seismic scenarios for the SS, SD, and CS events mentioned above. Based on the statistics of the results obtained for those scenarios, we proposed: mean (M), M + one standard deviation (S), and M + 3S, horizontal and vertical seismic design spectra to be utilized in the seismic design of the existing, or planned infrastructure of the oil industry facility. The economical implications of the proposed design spectra were analyzed based on the expected losses associated to the temporary closing down of the facility for different life expectancies of the latter.

### APPLICATION OF DEAGGREGATION METHODS IN PROBABILISTIC RISK MODELS – ID 2003

*F. Matter, Converium Ltd, Switzerland*
*E. Ruettener, Converium Ltd, Switzerland*
*A. Zbinden, Converium Ltd, Switzerland*

Deaggregation has become a standard methodology in probabilistic seismic hazard analysis. Determining the contribution from specific sources and their respective event magnitudes leads to a better understanding of the seismic hazard itself. This dissection allows the main risk driving elements to be identified and the most important parameters to be defined.

Deaggregation analyses are not limited to seismic hazard evaluations. They can be extended to hazard modelling of other natural perils, as well as to probabilistic loss modelling as applied in the insurance and reinsurance industry.

The possible applications are manifold: From identifying the magnitudes that contribute most to the expected loss or distinguishing the key parameters that dominate the loss estimates at a given return period (VaR) to the optimisation of (re-)insurance portfolios.

This work will provide an overview of the deaggregation methodology applied and especially emphasise the importance of discretisation steps and resolution. Examples and practical applications will be displayed and discussed.

### ESTIMATION OF GROUND MOTION AND REGIONAL SITE RESPONSE IN ITALY AND CENTRAL EUROPE – ID 2030

*T. Onur, Risk Management Solutions, Inc, United States*
*M. Nyst, Risk Management Solutions, Inc, United States*
*C. Williams, Risk Management Solutions, Inc, United States*

As part of an overall seismic risk and loss model development for Central Europe, we estimate ground motions for Italy and other selected European countries including Germany, Switzerland, Belgium, and Austria. The source modelling part of this project is discussed in a separate presentation (Nyst et al., 2006, abstract no. 2019). The first component of the ground motion estimation is the selection of strong motion prediction equations that are: i) relevant to the tectonic setting of the region, ii) based on locally recorded ground motions, and iii) suitable for modelling losses from large earthquakes. For low to moderate seismicity

regions, it is often challenging to satisfy all these conditions using a single model. Hence we investigated multiple ground motion attenuation relationships that, as a combined set, provide robust estimates. The second component of understanding ground motions is reflecting local site conditions on the reference motions. For this, we compiled available subsurface geology information at a regional level as well as an extensive collection of surface geology maps at varying scales (1:25,000 to 1: 500,000). Based on the surface and subsurface geology information available, we then assigned site classes to each of the map units. A NEHRP-like approach was then applied to estimate short-period and long-period site amplifications. The resulting ground motions including the local site conditions were compared to observed ground shaking intensities from past earthquakes in the region in order to ensure the reliability of the model and fine-tune modelling assumptions. Although the loss modelling methodology utilised for this project is based on spectral accelerations, peak ground acceleration and intensity based ground motions are also generated to allow this comparison.

## SS 4: ESC-UNESCO Workshop on Earthquake Hazard and Seismic Risk Reduction : Studies in the Southern Mediterranean Countries

Level-1

### PREDICTED AND OBSERVED PGA VALUES IN THE BOUMERDES (ALGERIA) AREA – ID 57

*Y. Bouhadad, CGS, Algeria*
*A. Slimani, CGS, Algeria*
*N. Laouami, CGS, Algeria*

During the main shock of the recent damaging 21st May 2003 Boumerdes earthquake (Mw = 6.8) (Central Northern Algeria), the Algerian accelerographs network, monitored by CGS, recorded strong motions at near and far fields by 13 stations. Before this earthquake, a probabilistic seismic hazard analysis has been performed in this area. A seismic source model based on the most recent seismotectonic studies and widely known attenuation laws of Ambraseys and Bommer (1991) and Sadigh et al. (1993) were used. One proposes, in this study to compare the observed and the predicted PGA values and, hence, discuss the reliability degree of the seismotectonic model and the chosen attenuation laws.

Key-word : Algeria, Strong Motion, Seismic Hazard, Seimotectonic, Reliability.

### SITE RESPONSE FROM MICROTREMOR AND 1-D MODELS FOR MICROZONING THE TOWNS OF DIMONA AND BET SHEAN, ISRAEL – ID 151

*Y. Zaslavsky, Geophysical Institute of Israel, Israel*
*G. Ataev, Geophysical Institute of Israel, Israel*
*M. Gorstein, Geophysical Institute of Israel, Israel*
*T. Aksinenko, Geophysical Institute of Israel, Israel*
*M. Kalmanovich, Geophysical Institute of Israel, Israel*

The densely populated towns of Dimona and Bet Shean, Israel are located close to the Dead Sea Transform. The main objective of the present study was development of 1-D models needed as input for seismic hazard assessment. Single station microtremor measurements were conducted at 200 sites in each town and maps were developed, showing distributions of the fundamental frequency and maximum values of H/V spectral ratios. The soil sites exhibited H/V maximum amplitude level ranging from 2 to 7 in the frequency range 1.5 to 9.0 Hz for Dimona and from 2 to 8 in the frequency range 0.5 to 15 Hz for Bet Shean. 1D models require S-velocity and thickness information, which was essentially unavailable. As a starter, a few refraction surveys were carried out at selected locations. 1D models based on the results of these surveys were utilized for theoretical derivation of site response, using SHAKE code. These agreed quite well with the H/V ratios for points located along the refraction lines in the frequency range corresponding to the fundamental mode. Subsequently, for areas with no borehole and refraction data, we applied, on the basis of extrapolations and geological reasoning, partial constraints – primarily on velocities. Within these constraints we searched for 1D models giving a calculated site response with the best fit to the H/V curve. Thus, H/V ratios effectively yielded constraints on the possible thicknesses of subsurface layers. Consequently, the microtremor measurements allowed identifying, tracing and estimating vertical displacements of a series of faults in the Bet Shean area, which is characterized by complicated fault-block basement morphology. However, the main value of this work was in that all results were tied to actually measured site effects, thus leading to more realistic site-specific seismic hazard assessments in these towns, in spite of the paucity of borehole and refraction data.

### SEISMICITY AND SEISMIC HAZARD ANALYSIS IN ESFAHAN QUADRANGLE – ID 156

*M. Sedghi, azad university, Iran (Islamic Republic Of)*
*M. Zare, international institute of earthquake engineering, Iran (Islamic Republic Of)*

The seismicity of Alpe-Himalya belt and specially in Iran plate is so important and questionable in seicmic survey and hazard analysis for the countries, located in this region.The more our knowledge grow on how an earthquake happens , the more exact will be the earthquake hazard survey in regional scale and special analysis on structural engineering and also the seismic zonation maps. Developing maps for seismic hazard is based on probabilistic seismic hazard analysis using the historical and instrumental earthquake data analysis, geological and tectonic data , fault activity and seismic source zones. These map have been prepared in the form of iso acceleration countour lines and seismic hazard zonation and show probable hazard analysis for return period of 75 and 475 years. Probablistic seismic hazard evaluation is consisted of determination of magnitutes , site condition and number of disasterous earthquake in the region and also PGA evaluation seismicity analysis or earthquake happening in exact site and time is the basis for all seismic hazard analysis methods. The subject region located in North-Central Iran .For preparing the seismic hazard map , first , the tectonic of this region was the subject of study and the tectonic map was prepared based on the faults of the region.Second , seismotectonic of the region was studied and the map was prepared , using the available catalogues , historical and instrumental earthquake data . Then the region was devided in to several zones and seismic hazard parameters were calculated for each of the zones individually usig the data sets including :Faults , earthquakes of the region and also geological information and the process tectonic of structures . The Iso acceleration map was finally prepared for the subject region at the point of 25km ×25km using a written computer code based on the parametic seismic hazard analysis using the probabilistic approach.

### SEISMOTECTONICS AND SEISMIC HAZARD ASSESSMENT OF THE ZANJAN PROVINCE IN IRAN – ID 561

*A. Mahdavian, Power and Water University of Technology (PWUT), Iran (Islamic Republic Of)*

This research is a part of the Iranian Seismic Hazard Assessment Program. The Zanjan Province is located in the north west of Iran with several active faults. Seismic Risk map of this area were made by using the Seismic data of the past and seismo-tectonic studies. Seismic parameters such as $\beta$ and $\lambda$ and also return period of Magnitude earthquakes estimated. This research improved the integration of the geological input in seismic hazard assessment. We applied several attenuation models and deterministic and probabilistic approaches throughout the Zanjan area. The maps of the area include the maximum acceleration (g) on the base rock. The return Periods of those maps are 200, 500, 2500, 5000 and 10000 years respectively. Finally, the hazard zonation map has been

presented for Zanjan area and classified to four zones with low, moderate, high and very high seismic zones. The Design Response Spectra with several return periods presented for these zones.

### INFLUENCE OF THE VRANCEA EARTHQUAKE FROM 4.03.1977 ON TERRAINS WITH ESTABLISHED PALEOSEISMIC EVENTS – ID 761

*D. Angelova, Bulgarian Academy of Sciences, Bulgaria*

More than 100 local paleoseismic events that occurred prior to the historical stage (8000 B.P.) were localised in Bulgaria during the last 15 years. They had been established in various morphostructural zones with diverse seismic-tectonic characteristics in contemporary plan, radically different for the single paleoseismic events. In most of the cases these were one-act events but there were also events that been repeatedly reactivated during the Quaternary, the Historical and the Contemporary stage. The paleoearthquakes had left numerous and diverse effects: anomalous disturbances in the natural relief and the geological environment, hydrological and hydrogeological anomalies, impacts ond old engineering structures and historical monuments. The present works shows the results obtained as a result of the impact exerted by the Vrancea earthquake from 4.03.1977 on the terrains with established paleoseismic events on the territory of Bulgaria. An assessment is made for all contemporary geodynamic processes taking place in these areas.

### LIBYAN DIGITAL SEISMOLOGICAL NETWORK AS FIRST DATABASE FOR LIBYA – ID 1653

*A. Elmelade, LCRSSS, Libyan Arab Jamahiriya*

Earthquakes are the most typical phenomenon of natural hazard. They have effects on nature, human life and man made structures. Assessment of earthquake occurrence sequences for any area plays an important role in proposing measures to minimize earthquake damage. Libya is located close to one of the continental fracture system (Hellenic arc) at the convergence boundary of two big lithospheric plates (Eurasia and Africa). Thus it could be concluded that although the damaging earthquakes occurred infrequently, its risky consequences could not be ignored. The compilation of a regional catalog of instrumental seismicity is one of the main products that the Libyan Digital Seismological Network (LDSN) has targeted to produce. The Libyan Center for Remote Sensing and Space Science (LCRSSS) with cooperation of UNESCO took charge of establishing a seismological network to monitor seismological activities, to create a data bass catalog for future researches in reducing seismic hazard. The work started in September 2004, by installing ten three component broad band stations, followed by another five stations in the mid 2005, distributed all over the country, especially in the active regions in Libya. A general idea about Historical and recent seismicity of Libya and the Libyan Seismological Network project will be given, with some examples of recorded earthquakes in the region.

### THE INFLUENCE OF B-VALUE ESTIMATE IN SEISMIC HAZARD ASSESSMENT – ID 1936

*L. Gulia, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*C. Meletti, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

In any probabilistic seismic hazard assessment, an important role is played by the seismicity rates. This is confirmed by the wide and controversial discussions about the procedures for determination of them: Gutenberg and Richter distribution or independent rates in every magnitude class, size of binned magnitude class, least squares or maximum likelihood fit, and so on. In 2004 a new seismic hazard reference map of Italy (MPS04) has been released adopting a logic tree approach for exploring the alternative epistemic choices. One of these choices was about the modality for compute seismicity rates: in the branches where Gutenberg and Richter distribution (GR) were adopted, the corresponding b-value was evaluated for each source zone, ranging from 0.63 to 2. These results appeared in contrast with the affirmation of the authors that the b-value is equal to 1 on a worldwide scale and for large volumes; on the other hand many papers pointed out the spatio-temporal b-value variability related to different parameters, the local stress regime amongst others. In this work it has been evaluated the effect of the equal to 1 b-value on the results of seismic hazard assessment. Two different approach have been used: i) the a-value in the GR distribution derive from MPS04; ii) the a-value has been evaluated in each source zones adopting the least squares method to fit individual rates. The first case involves a redistribution of earthquakes in the magnitude classes in comparison with MPS04, while the second one produces a new a-value, that means a different cumulative number of earthquakes. The resulting maps have been compared to MPS04, both in terms of expected PGA and of energy balance. The analysis also shows the effect with respect to the weighted median values, and pertinent uncertainties, produced by an integrated logic tree.

### THE 21ST MAY 2003, MW 6.8 BOUMERDES EARTHQUAKE. ALGERIA. POSTSEISMIC MODELLING FROM GPS OBSERVATIONS – ID 1960

*A. Mahsas, CRAAG, Algeria*
*K. Lammali, CRAAG, Algeria*
*P. Briole, IPG, France*
*E. Calais, Purdue University, United States*
*A. Yelles, CRAAG, Algeria*
*O. Charade, IPGP, France*

On 21st of May, 2003, a Mw= 6.8 earthquake occurred in the Boumerdès area, about 50km east of Algiers, capital of Algeria (Yelles et al. 2003, Ayadi et al., 2004). Few days after the event, a 6 GPS receiver network was progressively deployed with the collaboration of INSU (France), to monitor the post seismic displacements. 24 hours sessions observations, with 120s sampling rate have been processed using the Gamit software (King and Bock, 2003), including well-determined IGS sites as ties with ITRF 2000. For the station coordinates, phase ambiguities using double differenced GPS phase movements, with IGS precise orbits and IERS earth orientation parameters relaxed have been solved at each site. In this study we deduced the post seismic displacements from each site time series calculated within two years of observations of continuous data and we propose two models based on two different approaches. The Zemmouri fault is situated at the east termination of the Mitidja basin, limited by two main structures that have a potential seismic occurrence since there were no events since the 1825 earthquake (Rothé, 1950).

# Poster Presentations - From Thursday to Friday

## CS5: Site Response and Site Effects
Level 2

### SEISMIC HAZARD AND ALPINE VALLEY RESPONSE ANALYSIS : GENERIC VALLEY CONFIGURATIONS – ID 1

*C. Lacave, Résonance Ingénieurs-Conseils SA, Switzerland*
*F. Lemeille, Institut de Radioprotection et de Sûreté Nucléaire, France*

In the framework of the Interreg III-B European project called Sismovalp (Seismic hazard and alpine valley response analysis), a workpackage is devoted to the characterisation of "Alpine" valley configurations, by means of synthesis, acquisition and comparison of the geological and geotechnical parameters of some "pilot" alpine valleys. These valleys are Grenoble Isère river valley (F), Valais Rhone valley (CH), Bovec basin, upper Soca valley (Slo), Tagliamento river high valley (I), Gemona del Friuli (I), Val Resia (I), Val Pellice (I) and Val d'Aosta (I). All of these regions benefit from recent scientific work, fast building expansion and local authorities interest, which help the achievement of the project. The investigations conducted through the Sismovalp project include new geotechnical and geophysical studies necessary to characterise the pilot valleys. Information have been collected about the geological configuration and history of the valleys, including physical geography, geological and seismic history, available geotechnical and geophysical data, human activity (urbanisation, industrialisation), detailed geological description. A synthesis of all this information makes it possible to derive some generic alpine valley profiles as well as to build 2D and 3D models of some of the valleys. These profiles will be available on an open database. During the project, an important work to validate and document the geophysical methods used to explore the pilot valleys has been carried out. These codes (developed within several past projects but until now poorly documented) will be disseminated freely to the seismic engineering community in order to improve the quality of microzonations studies.

### SEISMIC LOCAL SITE EFFECTS STUDY FOR CHENNAI CITY, TAMIL NADU STATE, INDIA – ID 8

*S. Rajarathnam, Anna University, India*
*G. Ganapathy, Anna University, India*

Chennai city with population of 6 million experienced three earthquakes of M >5.0 in 1807, 1816 and 1823. The city has shallow water table and major part of the city covered by thick alluvium to the maximum depth of 28m. Such being the case, Chennai is liable for site-specific amplification of seismic motion. The safety of the buildings and infrastructures has evaluated based upon local ground motion response or local site effects.

Chennai is prone to M 5.8 (observed M 5.3 + 0.5 uncertainty) and the corresponding PGA is 0.21g. But the unconsolidated sediments overlying the basement at different depths in various part of Chennai leads to amplification of the PGA equivalent to Magnitude Max. in the range of 6.3 to 7.2 i.e the estimated increment of intensity of earthquakes is in the range of 1.1 to 3.4. The seismic hazard assessment for Chennai has been categorized based on the increment intensity as medium (VIII - <IX), high (IX - <X) and very high (X - <XI).The peak ground motion during shaking of different intensities (MMI) VII, VIII, IX and X are 0.10- 0.15, 0.25 - 0.30, 0.50 - 0.55 and >0.60 g respectively.

At present structures in Chennai city are being designed for seismic Zone III of Indian Bureau of Standard (IS 1893, 2002). This study shows that soil overlying the hard stratum in Chennai areas has capacity for amplification of earthquake energy as much as from 0.21g t 0.6g. For Zones III, IV and V the corresponding PGA is 0.20g. 0.25g and >0.49g. Though, overall seismic Zone III serves to be okay for Chennai. The high risk area where soil amplification will apply the PGA to 0.6g it may be worthwhile to consider designing the structure for higher zonation specification for Zone V.

### ASSESSMENT OF SITE EFFECTS AND GROUND MOTION LENGTHENING IN ISTANBUL – ID 53

*G. Birgoren, KOERI, Turkey*
*O. Ozel, KOERI, Turkey*

Estimation of site response in the city of Istanbul was investigated based on the data of four small earthquakes, recorded with Istanbul Rapid Response Network. Horizontal to Vertical Spectral Ratios (HVSR) and Standard Spectral Ratio Technique (SSR) were used to determine the predominant frequencies and relative site amplifications. Predominant frequencies which were verified by two different methods were presented at available sites. Lengthening of the ground motion was also investigated by group delay spectra considering that differences in group delay times among neighbor stations might be indicative of probable locations of more complex structures that necessitate further investigations. Examining these data, it was found that: (1) At European Side, most of the stations underlain by Alluvial deposits (Quaternary) have predominant frequencies between 1-2 Hz. (2) Predominant frequencies shift to larger values at stations at Asian Side. (3) Spectral shapes obtained from SSRT are generally in agreement with those obtained from HVSR (4) Relative amplification levels at stations located on Bakirkoy, Gungoren and Cukurcesme Formations change between 3-4 at 1 Hz. This level rises up to 7 on Cukurcesme Formation at 2 Hz. (5) Maximum amplifications at 3 Hz and 5 Hz, factors of 8-10 are seen on Cukurcesme formation and on Alluvial deposits, respectively (6) Group delay anomaly is detected at two regions. Delay time of stations located at European side is larger than those located at Asian side. Similarly, delay time of some closest stations to the epicenter have longer values than those calculated at farther stations. Predominant frequencies of those sites are between 0.7-2.5. This may imply that the group delay anomaly at those regions is the result of site response of thick sediments.

### AMBIENT VIBRATION MEASUREMENTS IN AQABA CITY, JORDAN – ID 60

*A. Khasawneh, Royal Scientific Society, Jordan*
*H. Al-Nimry, Royal Scientific Society, Jordan*
*T. Al-Hadid, Royal Scientific Society, Jordan*
*C. Lacave, Résonance Ingénieurs-Conseils SA, Switzerland*

Aqaba city, in Southern Jordan, is located on Dead Sea Transform fault a source of medium to high seismic activity, the city was affected by several large magnitude earthquakes throughout history, the most recent with a magnitude of 6.2 LM on the Richter scale on November1995. In the framework of a seismic microzonation of the area, 800 individual ambient vibration measurements were carried out in a grid (about 500m X 500m) covering Aqaba city. Data were processed using the horizontal to

vertical (H/V) spectral ratio technique. The fundamental frequency was calculated for each site. Throughout the measurements and analysis the guidelines developed for ambient vibration measurements by the EU funded project SESAME, were strictly adhered to. The fundamental frequency was compiled and corresponding maps were developed. The values of predominant frequencies where in the range of 0.2-1.0 Hz in Alluvium Sand, 0.2-1.5 Hz in Pleistocene Gravel and 0.65 HZ in coral deposits. The high number of noise measurements performed in the area of Aqaba allowed us to conclude that the adoption of the "Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibration Measurements, processing and Interpretation" developed through the SESAME European research project improved the quality of the signals recorded and analyzed and definitely boosted the confidence in the results, their accuracy and reliability.

Key words: Ambient vibration, dominant frequency, site effects, H/V ratio.

## TEST OF ENVIRONMENTAL NOISE IN BARCELONA CITY – ID 122

*R. Franklin, Universitat Politecnica de Catalunya, Spain*
*O. Caselles, Universitat Politecnica de Catalunya, Spain*
*J. Clapes, Universitat Politecnica de Catalunya, Spain*
*J. A. Canas, Universitat Politecnica de Catalunya, Spain*
*L. Pujades, Universitat Politecnica de Catalunya, Spain*
*F. García, Universidad Politecnica de Valencia, Spain*
*X. Lana, Universitat Politecnica de Catalunya, Spain*
*V. Perez-Gracia, Universitat Politecnica de Catalunya, Spain*

An unexpected damages observed in buildings after earthquake varies considerably from a construction to another, due to several factors. Among them, the structure seismic response and the seismic soil response. In order to measure ground amplification periods, the H/V Spectral Ratio technique is used, that it is based on the property that only the horizontal component may suffer amplification. Attributable to this effect, it is possible to consider that the H/V spectral ratio is a good estimator of the ground amplification periods. Nakamura (1989) proposed that it can be generalized to an environmental noise. The environmental noise is the superposition of ground vibrations produced by natural or artificial effects. At practical level, for the use of this technique it is necessary that the sources that generate the environmental noise most be distant, so that; the direct vibration is low in comparison with the resonance ground vibration. By this, it is necessary to realize the measurements in days without wind, enough distant to pedestrians, low transit of vehicles, and enough separation of buildings and trees. Specifically in Barcelona city, we have prove how the noise source distances affect the signal recorded evaluating them to avoid possible errors in future projects related with soil response. In this research, were considered the following experimental conditions: soft ground corresponding to Besòs river delta (Holocene, sands & silts) and hard ground corresponding to Tricycle (Pleistocene, clays, silts & calcareous crust). This work is the result of different tests that were made in Barcelona City to estimate the effect of distances from source to receiver.

## SITE EFFECT ESTIMATION FROM MICROTREMORS AND SEISMIC STRONG MOTION – ID 137

*N. Laouami, CGS, Algeria*
*A. Slimani, CGS, Algeria*
*N. Benkaci, CGS, Algeria*
*Y. Bouhadad, CGS, Algeria*

The quantification of the site effect, particularly the soil amplification, is an important step either for local seismic hazard evaluation or for the definition of input motion for structures seismic design. Generally, this estimation requires geophysical and geotechnical data which are not often available. In the last few years, many researchers adopt Nakamura technique for the evaluation of the soil amplification function using microtremors measurements. In this work, one proposes to evaluate soil amplification from microtremors, weak (PGA<10%g) and strong (PGA>10%g) motions by means of HVSR and RFT methods. Seismic data are provided from the main and after shocks of the 21 may Boumerdes earthquake (Mw= 6.8) and recorded at three sites. The results show that the estimated fundamental frequency is the same for both microtremors and seismic motion data, while the amplification factor is different. Indeed, it appears that the amplification factor increase significantly with the seismic motion intensity. Moreover, for the case of seismic motion data, other peaks are evidenced and attributed to high mode frequencies.

Key Words: Site Effect, Microtremor, Strong Motion, HVSR, Boumerdes Earthquake.

## THE DUAL RECIPROCITY BOUNDARY ELEMENT METHOD APPLIED TO 3D TRANSIENT HALF-SPACE DYNAMICS – ID 170

*K. Edip, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*
*M. Garevski, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*
*G. Schmid, Ruhr University, Germany*
*A. Tosecky, Ruhr University, Germany*

One of the solidly established numerical computational methods for modeling of unbounded media is the Boundary Element Method. It offers a wide branch of advantages for modeling of infinite and semi-infinite domains. Only few to mention are the boundary-only formulation of the problem resulting in considerable reduction of data amount to be processed and its intrinsic incorporation of regularity conditions at infinity, what is a vital feature in modeling of infinite and semi-infinite domains. In transient analysis, the time-dependent fundamental solution appearing in the mathematical formulation of the method leads to a convolution integral and in its numerical implementation to time-dependent system matrices. This unpleasant feature complicates seriously the numerical application, since new sets of matrices have to be calculated for each single time-step of analysis. The emersion of the convolution integral can be avoided, if the time-dependent fundamental solution used as a weighting function in the weighted residuals statement leading to the boundary integral equation, is replaced by an alternative, simpler and time-independent function. However, this gain gets on the costs of the dimensionality of the integration. Pure boundary-only formulation is no longer possible since one domain integral containing inertial forces over the whole domain appears in the formulation. This deteriorates the attractiveness of the method. Some measurements must be taken or otherwise we must cope with tedious and time-consuming volume integration. This issue seems to be even more important in modeling of infinite and semi-infinite domains, where the domain of integration actually extends to infinity. An efficient tool for transforming the domain integral into an equivalent boundary integral is the Dual Reciprocity approach. The strategy leading to boundary-only formulation comprising merely time-independent system matrices named as Dual Reciprocity Boundary Element Method (DRBEM) is described in the paper.

## SITE EFFECT MODELS DUE TO THE SHALLOW SEDIMENTARY ROCKS IN BUCHAREST METROPOLITAN AREA - ROMANIA – ID 172

*A. Bala, National Institute for Earth Physics, Romania*

New seismic measurements are performed in Bucharest area with the purpose of defining better physical and dynamic properties of the shallow sedimentary rocks. Down-hole seismic measurements were performed in a number of 10 boreholes with casing drilled in Bucharest Metropolitan area. Processing and interpretation of the data lead to the conclusion that shallow sedimentary rocks can be considered weak in the area, down to 100 m depth. Shear wave velocity values and natural unit weight values presented in the paper associated with local geology of Quaternary layers are useful primary data in the seismic microzonation of Bucharest City. A seismic signal recorded in a borehole at 100 m depth is used as input strong motion, considered the same for the entire study area. Input data are used to derive transfer functions for the stack of sedimentary rocks (down to 100 m depth)

in different parts of Bucharest, leading to a better knowledge of local site amplification. Acceleration response spectra are also computed, showing amplifications of the shallow sedimentary layers at almost the same frequency range, but with different values ( 1.1x – 2x ). Site effects with larger values of 2 – 3x can occur locally. These values are obviously dependent on the geologic composition of the sedimentary stack. The period values for the maximum amplification peaks correspond well with the known period domains from the accelerometer recordings in Bucharest, between 0.1 – 0.7 s for the strong motion applied. Acceleration response spectra computed by this method prove to be a valuable tool in evaluation of the seismic microzonation in Bucharest on the basis of physical and dynamic properties of the sedimentary Quaternary rocks encountered until 100 m depth.

### SEISMIC PERFORMANCE OF RIGID INCLUSIONS BUILT IN SOFT CLAY – ID 180

*J. Mayoral, Institute of Engineering, Mexico*
*B. Mendez, Institute of Engineering, Mexico*
*M. Romo, Institute of Engineering, Mexico*

Detailed numerical analyses are conducted to evaluate the seismic performance of groups of rigid inclusions-soil-structure systems built on soft clay deposits. A 3-D finite element model is used in this assessment. The model includes the effects of interaction among inclusions, the structure vibration and the presence of the distribution layer. The soil is represented as an infinite layered system and the structure as a shear beam to account for mass distribution effects. The inclusions are simulated as beam elements. The model is subjected to horizontal SH waves propagating vertically. Hysteretic and radiation damping are included explicitly in the analyses. Nonlinear soil response is captured approximately using the equivalent linear method. A parametric study is conducted to determine the influence of the inclusions diameters, the separation among them, and their length on their seismic performance, considering typical stratigraphic and seismic conditions prevailing in Mexico City. From the results of this evaluation practical design implications are obtained. The seismic performance of the inclusion groups during and after the earthquake are evaluated in terms of the spatial and temporal distribution of accelerations and seismic shear forces and bending moments acting on the inclusions. The analyses indicate that the system comprised by the distribution layer and the inclusions can reduce the amplitude of the accelerations observed at the ground surface. Most of this reduction is due to the presence of the distribution layer. Bending moment distributions of maximum values tend to reach a peak at the contact with stiff lenses typically found in Mexico City. These values can be higher than the cracking values computed for typical design conditions, potentially leading to dislocations that may impair the ability of the inclusions to control settlements after the earthquake, or to increase their vulnerability in future seismic events.

### 2D EVALUATION OF SITE EFFECT IN THE CITY OF BAM – ID 188

*M. H. Baziar, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*N. Tafazzoli, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*M. Fatemi Aghda, Natural Disaster Research Center of Iran, Iran (Islamic Republic Of)*

Evaluation of site effect is one of the most important problems, considered in the geotechnical earthquake engineering field. One of the applications of dynamic analysis of the site is to determine the shear forces applying to the structures. In many cases, the dynamic analysis for evaluation of site effect is performed using one dimensional model. However, one dimensional analysis is useful only for flat regions. In other words, in many cases, a site might be located on an alluvial valley and two dimensional analysis should be performed to obtain reliable results. Researchers have showed that in a valley area covered with sediments, one dimensional analysis can not simulate the reflection of the waves from the boundaries of the valley. The city of Bam, located in south of Iran, experienced a severe earthquake in December 26, 2003. Geotechnical investigations have showed that in some parts of the city, the height of the sediments are much higher than other parts, and the outcrop of bedrock can be seen in a few places of the city. Therefore, amplification of the motions can be varied in different regions of the city and two dimensional analysis is needed due to geology of the valley. In this research, some regions of the Bam city are modeled in one and two dimensions and the amplification of the motions are determined. The responses of the soil and the response spectrums in different models are also compared with each other. The results of the two dimensional analysis indicate that the amplification in some parts of the city are much higher than the other parts which coincide with the structural damages observed after the earthquake.

### MICROREGIONALIZATION AND INSPECTION OF BUILDINGS ON DATA OF SEISMIC OBSERVATIONS – ID 203

*F. N. Yudakhin, Archangelsk Scientific Centre UB RAS, Russian Federation*
*N. K. Kapustian, Institute of Physics of the Earth, RAS, Russian Federation*
*G. N. Antonovskaya, Institute of Ecological Problems in the North UB, Russian Federation*
*E. V. Shakhova, Institute of Ecological Problems in the North UB, Russian Federation*

Engineering design of modern buildings and multipurpose complexes demands specification previous and creations of new comprehensive microregionalization maps. Realization of the given works in city territories in conditions of the compact planning and with rigid ecological requirements, as a rule, is made with use of mikcrotremors. The new method based on allocation from mikcrotremors of monochromatic signals, caused by wind oscillations of high objects, including high-rise building was offered. Frequencies of these seismic signals correspond to eigen-frequencies of buildings, i.e. from 10 Hz and lower - up to 0.2-0.5 Hz. In seismic sense a building at wind loads is like the stationary seismic vibrator which is working in a monochromatic mode and prospecting city soils in radius up to ten kilometers. The method was tested at seismic microregionalization of the central part of Arkhangelsk city. Maps of increment acceleration which were compared with made earlier on the basis of borehole data have been received. Comparison has shown the close correspondence of maps. Other opportunity of using the wind oscillation is based on seismometric observations inside buildings in different points. On experimental examples a number of methods were shown. The first one consists in placing points of registration at one height of a building but in different points on length. It allows revealing a difference in properties of soils and their change in time. The second method is based on the analysis of spectra structure response in different points and comparison of fields for a set of own frequencies and X, Y, Z a component of seismic registration. It allows revealing cracks and the weak zones in a building. The using of method for the buildings injured of explosion of household gas and at inspection of condition the historical monuments of the Solovetsky Island was shown.

### STRUCTURE-SOIL-STRUCTURE INTERACTION EFFECTS ON NONLINEAR DYNAMIC RESPONSE OF TALL BUILDINGS – ID 206

*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*
*A. Rezaei, ERC-TEHRAN, Iran (Islamic Republic Of)*

Numerous studies have shown that the interaction between adjacent buildings can result in changes in nonlinear dynamic response of structures, damage and performance level, depending on the dynamic specifications of structures involved and the frequency content of the input motion. Also studies have shown that depending on dynamic parameters, a massive structure can have an observable effect on the seismic response of a smaller and

less stiff structure.

To study this effect, finite element method is used for the analytical investigations. In this study, total soil-foundation-structure system is modeled all together and analyzed. For modeling purposes and in order to realize the effects of the adjacent buildings on the dynamic response, two buildings namely; 15 story and 30 story tall buildings located on hard and soft soil profiles were considered. These two buildings were separated by distance of 1/4 and 1/8 of the width of the foundation.

It was concluded that in the case where soil and structure's period were near each other, the interaction of adjacent structures on increasing the nonlinear responses (displacement and interstory drift) and structural damage indexes were noticeable, therefore not negligible. Whereas, in the case where periods are distant from each other, interaction of adjacent buildings has a decreasing effect on damage indexes and the nonlinear responses, therefore negligible. Theoretical, analytical and results obtained in this study will be presented in this paper.

### THE RELATIVE IMPORTANCE OF SITE EFFECTS IN SEISMIC HAZARD ANALYSIS – ID 227

*G. Leonard, IAEC, Israel*
*D. Steinberg, TAU, Israel*
*N. Rabinowitz, Technitzan, Israel*

Damage from strong earthquakes often exhibits local variation. Ground motion prediction equations have been developed that take account of such so-called site effects and they have been used in assessing seismic hazard. However, many authors have concluded that the ability to accurately reflect site effects in prediction equations is limited. This work describes a method for assessing the importance of site effects relative to that of magnitude, distance and residual uncertainty in predicting strong ground motion. The ideas are illustrated by carrying out some comparisons using the ground motion prediction equations of Boore et al. (1997).

### EMPIRICAL ESTIMATES OF SITE AMPLIFICATION FACTOR FROM STRONG-MOTION RECORDS AT NEARBY STATION PAIRS – ID 251

*K. Fujimoto, Chiba Institute of Science, Japan*
*S. Midorikawa, Tokyo Institute of Technology, Japan*

This study focuses on evaluating the empirical relationship between site amplification factor and average shear-wave velocity of ground to a certain depth. In the previous studies on the relationship, amplification factors are often inferred from empirical attenuation equation. Such amplification factor is affected by not only the local site condition but also the source radiation pattern, wave propagation path, and directivity. In this study, a method for estimating the site amplification factor from the peak amplitudes of ground motion recorded at nearby station pairs at the same event, which can reduce the effects of source and propagation path on amplification factor, is proposed. This method is applied to the strong-motion recordings of K-NET and KiK-net for several large earthquakes in Japan such as the 2000 Tottori-ken Seibu earthquake (Mw6.6) and the 2001 Geiyo earthquake (Mw6.8). To complement the strong-motion records at higher intensity levels, strong-motion data from the 1989 Loma Prieta earthquake (Mw6.9) and the 1994 Northridge earthquake (Mw6.7) are also incorporated in the data set. In order to investigate the nonlinear effect on site amplification factor, the relationship between amplification factor estimated from the method using the entire data set and average shear-wave velocity calculated from borehole shear-velocity logs is examined in terms of shear strain in surface soils. The results indicates that the effect of nonlinearity on amplification factor for peak ground acceleration becomes significant with the strain level in surface soils being larger than approximately $3\times10\wedge$-4 whereas the nonlinear effect on amplification factor for peak ground velocity is not apparent up to the strain level of about $1\times10\wedge$-3. An empirical equation for predicting the site amplification factor in terms of average shear-wave velocity in the upper 30 meters, which considers the nonlinear effect of ground shaking, is proposed.

### SITE EFFECTS, DATA PROCESSING AND RESPONSE SPECTRA DUE TO THE 1999 KOCAELI AND DUZCE EARTHQUAKES – ID 279

*P. Gundes Bakir, Katholieke Universiteit Leuven, Belgium*
*G. De Roeck, Katholieke Universiteit Leuven, Belgium*
*G. Degrande, Katholieke Universiteit Leuven, Belgium*
*R. Iyisan, Istanbul Technical University, Turkey*

The 1999 Kocaeli and Duzce earthquakes were among the most catastrophic earth- quakes in Europe in recent history. This study examines the site effects and response spectra due to these two earthquakes. Since Istanbul carries the highest risk in Europe, the districts of Istanbul that are especially susceptible to site amplification hazard are determined. Both classical spectral ratio (CSR) and the receiver function (RF) methods are employed. The CSR method gives higher estimates for the site amplifications compared to the RF method and is in better conformity with the observed damage during the Kocaeli earthquake. The results also show that the site amplification hazard risk is the highest for Ambarli and Yesilkoy districts in Istanbul. It has long been argued by the earthquake engineering community that although liquefaction is a potential hazard to the stability of sites, it may be beneficial to structures by providing a natural base isolation and this was the reason why many structures at Adapazari were subjected to liquefaction induced foundation displacements without serious structural damage. However, this study shows that for sites which have the risk of soil amplification for long period structures, liquefac- tion may not be beneficial as a natural base isolator and may result in shifting the eigenperiod of the low and mid rise structures to the critical periods with high site amplifications. This may be especially the case for Avcilar and Yesilkoy districts. In Fatih and Cekmece districts, the predominant period of the ground motion is very close to the eigenperiods of the typical residential buildings. Therefore, these two districts are expected to experience heavier damage in future earthquakes due to resonance effects.

### PROPOSAL OF NEW EQUIVALENT LINEAR ANALYSIS TECHNIQUE FOR PRECISE VERTICAL MOTION SIMULATION – ID 322

*H. Sato, CRIEPI, Japan*
*M. Kanatani, CRIEPI, Japan*

In this study, we proposed new equivalent linear analysis technique introducing complex bulk modulus to consider Qp because it was necessary to evaluate vertical motion more precisely during large earthquake by equivalent linear analysis using the input of the horizontal and the vertical motion simultaneously. In the proposed technique, following points were newly introduced into equivalent linear analysis technique. 1. Complex bulk modulus is introduced without Poisson's ratio, and complex bulk modulus is assumed to be constant under strong and weak earthquake motion. 2. Damping factor is defined by the sum of the material damping and the frequency dependence damping (scattering attenuation), and the frequency dependence damping factor is assumed to be constant under strong and weak earthquake motion. The proposed technique was applied to strong motion simulation during 1995 Hyogo-ken-nanbu earthquake for demonstrating high performance of this technique. From the analytical result, P-wave velocity and Qp that mainly influenced vertical motion simulation has hardly changed during strong motion same as well as actual phenomena derived strong motion observation records. Moreover, it was demonstrated that proposed technique was in more good agreement with the observations than present technique. Therefore proposed technique has a high performance in the purpose to evaluate the vertical motion more precisely.

### SITE AMPLIFICATION PREDICTIONS USING RANDOM VIBRATION THEORY – ID 337

*E. Rathje, U. Texas, United States*
*M. C. Ozbey, U. Texas, United States*

*A. Kottke, U.Texas, United States*

Random vibration theory (RVT) has been used by seismologists for some time to predict earthquake ground motions. However, this technique has not permeated into geotechnical earthquake engineering, although it is a potentially powerful tool that can be applied to traditional equivalent-linear site response analysis to predict seismic site amplification. Here, the main advantage of RVT is that one does not need to select any input rock motions for the analyses. This paper introduces the basic concepts of RVT, as applied to site amplification prediction, and compares RVT-based site amplification estimates with those from traditional site response analyses using time domain input motions.

RVT site response analysis involves characterizing the input rock motion with only a Fourier amplitude spectrum (FAS), propagating this spectrum to the ground surface using frequency domain transfer functions, and predicting the peak time domain characteristics of motion (e.g., peak ground acceleration, spectral acceleration) using extreme value statistics. The input FAS can be prescribed based on a seismological model (e.g., Brune spectrum) or it can be derived from an acceleration response spectrum, and thus no input time histories are required.

A soft soil (Treasure Island) and a deep soil (Sylmar Converter Stations) site are considered for the analyses, and comparisons are made between RVT and traditional time history analyses for two earthquake scenarios representing different intensities of shaking. In general, the comparisons between RVT and the traditional analyses are favorable, but RVT appears to overpredict amplification at the site period by 10 to 20%, as compared to the results from time domain analyses. These results indicate some modifications to RVT may be required to produce accurate site response predictions.

## A STUDY ON LOCAL DAMAGE DISTRIBUTION DURING THE 2004 NIIGATAKEN-CHUETSU EARTHQUAKE – ID 342

*T. Maeda, Waseda Univ., Japan*
*E. Nagashima, Waseda Univ., Japan*
*R. Shimizu, Waseda Univ., Japan*

In 2004, we had the disastrous Niigataken-Chuetsu earthquake of M 6.8. Acceleration records of more than 1G were observed at several stations. In Tokamachi-city, which is located about 20km south from the epicenter, more than 1,700 Gal was observed at NIED's K-NET station, whereas only light damage was found at nearby school buildings and houses. We suspect that the cause of that high acceleration might be attributed to some local effects and carried out micro-tremor array observation at the ground of Tokamachi-minami junior high school, where the observation station is located.

Applying the neighbourhood algorithm for joint inversion on dispersion curves and H/V spectra, we evaluated a subsurface structure model of the school ground. The model simulates predominant frequency of 6.5Hz of the micro-tremor H/V spectra, which may have been lowered to about 4 Hz of predominant peaks for strong motion power spectra of the main shock and major after shocks. The change in predominant frequency suggests that the decrease of rigidity due to non-linearity during the main shock is about 40% of that of small strain level. Effective shear strain is deduced to be 0.3 % by examining strong ground motion records with assumed one-dimensional vertical wave propagation. The relation between the reduced rigidity and the effective shear strain follows well-calibrated conventional diagrams, and we conclude that the inconsistency between low damage and high PGA is attributable to high frequency amplification caused by the reverberation due to the local subsurface structure.

Tokamachi-city is not a large city, though there certainly were differences in damages due to local site effects. We also carried out mobile micro-tremor observation throughout the city to find that the damaged downtown area have lower predominant frequency of around 2 Hz compared to the station area, which can explain damage concentration in the downtown.

## ESTIMATION OF PEAK GROUND MOTION DISTRIBUTION USING OBSERVED RECORDS DURING THE CHUETSU EARTHQUAKE – ID 346

*I. Suetomi, NIED, Japan*
*E. Ishida, Japan Engineering Consultants Co.,Ltd., Japan*
*Y. Fukushima, Japan Engineering Consultants Co.,Ltd., Japan*
*R. Isoyama, Japan Engineering Consultants Co.,Ltd., Japan*
*S. Sawada, Kyoto University, Japan*

A realtime monitoring system has been installed to support disaster emergency activity in the early post disaster environment by many organizations after the 1995 Hyogoken-Nambu earthquake in Japan. Amplification characteristics of the shallow soil deposits are very important to evaluate ground motion distribution with seismometry network. However, it is not easy in a severe earthquake to get an appropriate evaluation immediately because of nonlinear behavior of the ground. In this paper, we suggest a new model reflecting nonlinear behavior of the soil adequately. In order to consider nonlinear characteristics of soft ground, we propose a new amplification function which has four parameters such as an amplification factor during weak motions and the upper limit depending on shear strength of the soil deposits. Earthquake response analyses are carried out with many conditions and 4 parameters are decided. Topography classifications and a predominant period have been often used as ground parameter, but in late years the use of average S-wave velocity increases. Therefore, we connect average S-wave velocity to 20m or 30m deep with four parameters in order to apply to the area where boring data are provided to high density. Many strong ground motions were recorded during the Niigata Chuetsu earthquake on October 23, 2004. It was the first observation that JMA instrumental seismic intensity was 7. We calculated a high-accuracy map of peak ground motion by interpolation method using the observed records with many borehole data.

## NUMERICAL SIMULATION OF EFFECTS OF LIQUEFACTION IN SEISMIC SSI – ID 368

*F. Lopez-Caballero, Ecole Centrale Paris, France*
*A. Modaressi, Ecole Centrale Paris, France*

Traditionally, in the earthquake engineering practice the soil-foundation-structure interaction phenomenon is studied with the assumption of the linear elastic behaviour for the soil. It is also well known that the seismic response of a structure can be significantly altered by the flexibility of its soil foundation. In the case where an elastic soil behaviour is assumed, the surface motion will be amplified proportionally to the input motion. However, in reality the amplitude and frequency content of the response are modified due to the soil's stiffness degradation and higher energy dissipation. The quantification of local site effects on the input ground motion is of particular importance for earthquake resistant design as well as for the evaluation of seismic damage risk of existing structures. In this work, the influence of soil non-linearity, introduced by the liquefaction, on the soil-foundation-structure interaction phenomena is evaluated. Several single-degree-of-freedom structures founded on a flexible shallow foundation are chosen to reveal, with great simplicity, the beneficial or unfavourable effects of the soil-structure interaction phenomenon. Thus a 2D coupled finite element modelling is carried out using an elastoplastic multi-mechanism model to represent the soil behaviour. For a given site, appropriate input ground motions are chosen to enforce the inelastic behaviour of the soil. The role of several parameters on both the seismic ground acceleration under the foundation and the drift of structure are extensively studied. This parametric study concerns the mechanical properties of the structure (masse and frequency) as well as the characteristics of the input motion (amplitude, frequency content and equivalent number of cycles). The simulations show that as far as it concerns the effect of soil liquefaction in the soil-structure interaction response, only for some ratios of fundamental frequency of soil and structure a great modification from the elastic condition appears.

## IDENTIFICATION SYSTEM OF DYNAMIC SOIL PROPERTIES USING VERTICAL ARRAY RECORDS OF GROUND MOTIONS – ID 467

*O. Tsujihara, Wakayama National College of Technology, Japan*
*T. Sawada, Tokushima University, Japan*

Strong ground motions are largely affected by the amplification effect of subsurface layers of the ground. Therefore, it is very important to estimate dynamic soil properties of subsurface ground in order to predict the characteristics of strong ground motion that influence the behavior of structures based on ground or lifeline facilities buried underground.

Recently, several studies have been done on the identification of dynamic soil properties of subsurface ground using the vertical array records of ground motions. Among those properties, the damping is known to be difficult in particular to be identified. While, vertical array observations of ground motions are energetically carried out in Japan. Digital strong-motion seismographs so called Kik-net are deployed by National Research Institute for Earth Science and Disaster Prevention (NIED) at over 600 sites. An enormous amount of data has been accumulated since 1997 and can be downloaded on the web site. They give us big chances to identify the dynamic properties of subsurface ground. In order to identify the properties using Kik-net data, however, some preprocesses such as the correction of sensor direction, wave synthesis, drawing wave, preparation of soil data are needed. Furthermore, the selection of the interval of time series, damping model and initial values used in the analysis of identification must be investigated, because they influence on the results of identification. Moreover, some postprocesses such as drawing spectra are also required.

The purpose of this study is to develop the system of identification of dynamic soil properties using Kik-net. It is free from most of the troublesome operations, which makes the various analyses on the different conditions possible. In this paper, it is demonstrated how this system is effective to identify and accumulate the dynamic soil properties in the quake using Kik-net.

## COMPARISON OF EARTHQUAKE RESPONSE ANALYSIS OF GROUND FOCUSING ON DAMPING – ID 472

*N. Yoshida, Tohoku-Gakuin University, Japan*
*S. Sawada, Kyoto University, Japan*
*S. Nakamura, Nihon University, Japan*

Comparisons of nonlinear earthquake response analyses of ground are made by focusing on velocity proportional damping and hysteretic damping. In order to use the same velocity proportional damping in frequency and time domain analyses, equivalent linear analysis is improved to be able to use frequency dependent damping and time domain analysis is improved to use modal damping. In addition, improved equivalent linear analysis are employed in order to overcome two big shortage than conventional program SHAKE has in order to compare truly nonlinear analysis under the same stress-strain model. A site in Tokyo city is used as an case study. Almost identical results are obtained under the elastic analysis, which ensure the improved method. On the other hand, frequency proportional damping is show to have tendency to suppress displacement, especially when nonlinear behavior becomes predominant.

## EFFECTS OF NONLINEARITY OF THE SOIL BEHAVIOR IN STRONG GROUND MOTION – ID 476

*O. Pavlenko, Institute of Physics of the Earth, Russian Federation*

Nonlinearity of the soil behavior in strong ground motion was studied based on records of the 1995 Kobe and the 2000 Tottori earthquakes, provided by seismic vertical arrays. The following conclusions were made. Nonlinearity of the soil response leads to changes in spectra and amplification of oscillations on the surface. Changes in spectra appear in: (1) decrease in resonant frequencies of the soil layers (due to soil softening caused by the strong motion), (2) generation of combination-frequency harmonics and sub-harmonics of the main frequencies of propagating waves (due to interaction and self-modulation of the waves), (3) tendencies of smoothing of spectra of oscillations on the surface and transforming them to the form E(f) f -k (due to the nonlinear absorption of waves at high and average frequencies and wave interaction). In practice, seismic waves with any spectral composition, propagating up to the surface through soft soil layers, tend to be transformed into waves with spectrum E(f) f -k; in other words, in subsurface soils intense seismic waves loose (partially or completely, depending on the degree of nonlinearity) information on their spectral composition. Amplification of seismic waves is decreased in cases of nonlinear soil response (compared to the linear response) in dry soils (underground water level is below 10 m) and, less noticeably, in wet soils; in the latter case, nonlinear weakening of the waves can be compensated by their amplification by linear mechanisms, and in the whole, oscillations can be amplified. Limitations of many existing programs for soil response estimation are: disregarding differences in the nonlinear behavior of different types of soils and disregarding possible changes in rheological properties of the upper soil layers, caused by the strong motion. The size of the area of strong manifestations of soil nonlinearity is 1/4 of the length of the fault plane.

## DETERMINATION OF S-WAVE VELOCITY STRUCTURE USING ARRAY MICROTREMOR MEASUREMENTS: CONVENTIONAL AND TWO-SITE SPATIAL AUTOCORRELATION METHOD – ID 478

*S. Margaryan, Building Research Institute, IISEE, Japan*

Site effect is one of the important subjects in engineering seismology and to perform the assessment of the site effect it is necessary to estimate subsurface structure. In recent years for estimation of S-wave velocity structure, which is more valuable than P-wave velocity structure from engineering standpoint, microtremors array observation were widely in use. Based on a microtremor method with seismometer array, we determined geological structure of the Narita city near the border of Chiba and Ibaraki prefecture. Observations carried out at two different areas with different geological structures. We used conventional Spatial Auto-Correlation Method (SPAC) and two-site Spatial Auto-Correlation Method (2sSPAC) methods. In comparison with F-K (Frequency-wavenumber) method it allows as to survey the area with minimum set of seismometers. The first observation carried out on the rice-field with 7 sensors, with array size of 900 m, 300 m, 100 m, 30 m and 15 m. In this site we used only SPAC method. Second observation carried out on the school ground area, which is located about 1.0 km from the rice-field, where the surface soil is harder than that of rice-field. In the second case we deployed 7 sensors, with array size 100m and 50m and used both SPAC and 2sSPAC approaches. In both cases we used equilateral triangle array and only vertical component of sensors. Using spatial auto-correlation method we measured phase velocities of fundamental mode Rayleigh waves in microtremors. The observed phase velocities were inverted into geological structure of S-wave velocity. The comparison of phase velocities obtained by SPAC and 2sSPAC methods allowed concluding that 2sSPAC method is also provide reasonable values for phase velocities.

## RESPONSE OF SELECTED SITES IN KARVINA REGION DURING MINING INDUCED SEISMIC EVENTS – ID 485

*Z. Kalab, Institute of Geonics, Czech Republic*
*J. Knejzlik, Institute of Geonics, Czech Republic*

Knowledge of local geology is fundamental to evaluation of seismic response of given building object or to start preparation of mathematical model with realistic results. Karviná region is our investigated area because it is known as locality with very intensive mining induced seismic events. This seismic effect on free surface reached up to 15 mm.s-1 and number of events per year with magnitude higher than 1 ranged from 100 to 300 usually. Mining tremors are one of the most important causes of damages and acceleration of technical wear of buildings on mining area. These effects are often theme of discussions and contentions, especially if people or housings are in surroundings of underground exploitation.

Vibrations are often regarded as the reason of damages on the buildings.

Local geological conditions are very complicated due rapid changes of sedimentary layers that in investigated area (10 x 8 km) ranged from zero (outcrop of Carboniferous rocks) to more that 600 m. To evaluate selected sites on seismic loading we start monitoring on these sites with different thickness of sedimentary layers (Tertiary and Quaternary ages). Using Nakamura´s methodology we computed spectral ratios for measured points. Obtained results document very different shape of these ratio curves.

### INTERCONNECTION OF SOIL NONLINEARITY AND RESONANT AMPLIFICATION OF SEISMIC WAVES IN SOIL LAYERS – ID 493

*O. Pavlenko, Institute of Physics of the Earth, Russian Federation*

Resonant amplification of seismic waves in soil layers and nonlinearity of the soil behavior in strong ground motion are basic physical mechanisms defining seismic wave transformations in subsurface soils. These phenomena are descriptively illustrated by numerical models of the nonlinear soil behavior during the 1995 Kobe earthquake and the 2000 Tottori earthquake, which were constructed in our previous studies. The models represent vertical distributions of stresses and strains in the soil layers, changing in time during the strong motion; they were constructed based on records of the strong earthquakes, provided by seismic vertical arrays. A good agreement between the observed and simulated accelerograms at depths of locations of vertical array transducers testifies to the validity of the obtained representations. The constructed models of the soil behavior were used in numerical experiments aimed at studying the effects of nonlinearity in seismic wave fields. The following results were obtained: (1) a substantial decrease (several times) in resonant frequencies of the soil layers with increasing the intensity of the input motion was estimated for various soil profiles, including profiles with smooth growth of seismic velocities with depth; (2) effects of self-modulation of seismic waves and generation of sub-harmonics were observed at resonant frequencies, i.e., in cases of resonant amplification of seismic oscillations in soil layers; we attribute this to the appearance of dispersion of seismic wave propagation velocities, caused by nonlinearity of the soil response. According to the nonlinear wave theory, effects of self-modulation of intense waves are typical for nonlinear media with dispersion. Thus, the conditions are determined of the appearance of the nonlinear seismic effects of self-modulation of seismic waves and sub-harmonic generation, which, along with higher harmonic generation, defines nonlinear changes in spectra of intense seismic waves, propagating in subsurface soils.

### ONE DIMENSIONAL LINEAR SITE RESPONSE ANALYSIS IN BAM – ID 576

*M. Ashtari Jafari, Tehran University, Iran (Islamic Republic Of)*
*M. R. Hatami, Tehran University, Iran (Islamic Republic Of)*

On 26 December 2003 a great earthquake scaling Mw equal 6.6 has completely destroyed the ancient city of Bam located south eastern of Iran in the province of Kerman. Standing historical citadel of Arg-e-Bam with about 2000 years old might be a sign that the area has not experienced great earthquakes before this shock; although there are some great earthquakes in and around the province of Kerman not very far from Bam. The focal mechanism of this event was reported as steeply dipping right lateral strike slip that was firstly considered to be caused by movement on the Bam fault but later it was assigned to shakings on an unconsidered fault; newly named the Arg-e-Bam fault. The city was severely damaged because of the poorly constructed houses of unreinforced mud bricks, although the damage was unexpectedly heavy in comparison with the magnitude of the earthquake. It is well known that frequency content and amplitude of ground motion can be greatly affected by type and configuration of near surface material. On the other hand seismic hazard estimations need effects of crustal structure, rupture, surface geology, soil column thickness and nonlinearity. After collecting necessary data; in this paper the equivalent one dimensional site response analysis for the city of Bam has been made to derive acceleration, relative velocity and displacement, Fourier spectrum, response spectrum at the top of selected sub-layers and amplification factors. The results will be useful for present and future reconstruction of the same city and is a pilot project for a future nonlinear site response analysis.

### RESEARCH ON THE METHOD OF DETERMINATION THE TIME OF FORTHCOMING SEISMIC EVENT. – ID 589

*A. Galka, Geneva State University, Switzerland*

The “tiring - topology” Crone's ideas, the ideas of Sobolev's space and Sobolev's generalized derivative, the representations of the fundamental space for all physical fields as the Minkovsky space and the associated pseudo-euclid space - time (Mn) geometry, the definitions of the generalized thermodynamic potentials - vectors and charges-vectors, and also the Vlasov's kinetic equation together with the equations of Faraday-Maxwell had been used in the work. This has allowed finding the ways of calculation of the new forming structural formations entropy dynamics in the mantle, the lithosphere and the atmosphere as the solid process before the natural accident on the basis of Kolmogorov-Liapunov theory and the strange and fractional kinetics. Using the specially designed instrumental system indication data, and the mathematical calculation data had allowed the correct forecasting both coordinates and time of the earthquakes with C>6, flooding and other natural accidents realization via the reproduction of newly formed structures holograms as the forerunner of natural accident.

### PHYSICO-MATHEMATICAL BASE AND MONITORING SYSTEM FOR THE EARTHQUAKE FORECAST (M>6), ITS PLACE AND TIME – ID 609

*O. Martynov, Tula State University, Russian Federation*
*M. Martynova, "Prognoz", Russian Federation*

A disturbed system, in consequence of the energy conservation law, aspires to come back in equilibrium condition. Through bifurcation stages in the mantle, lithosphere and atmosphere the new structures arise . The strangeness and factualness(as self-organization characteristics) determine the multi-scale correlation by transition to the regime of chaos, controlled by the global gravitation fields. Processes of interacting on self-similar fractal multitudes (reflection of Point-Carre) are regulated by their topological invariants.The value limits of the entropy S=0,38-0,7 permits (by Liapunov) to determine the critical time.Fractons created by localized excitements accord with fractal geometry of the system and reflect in form of holographic phonons in VLF diaposon- <10 - 3Hz. During the process of chaos controlling the indications of transitions in diffusion's regime appear, what is characterized by the constant of stability C≃1,327, and by utmost value of system's entropy S 0.7(by Bolzmann-Plank) in the anticyclone situation in concrete geological and geo-morphological conditions. The monitoring of these processes is realized in real time scale by registration of the special aerial's readings of our devices (Kevendish-balance). Aerials fix the changing in gradients of the geo- structure's generalized thermodynamic potentials. The dynamic of the holograms is created on the base of these data. All mentioned and physico-mathematical models let us in 1999-2005 give out and send to the embassies in Moscow of european countries, Turkey, region of Caucasus, Iran opportune mid-time term and short-term forecasts about the forthcoming natural catastrophes on their territories with a precision of 100x100km. At present time we are working to extend the territory of monitoring till 5000 km from the place of our devices with determination of coordinates and the time of forthcoming event 70-100 hours before.

### SEISMIC RESPONSE OF ALPINE VALLEYS: THE CASE OF VAL PELLICE, ITALY – ID 636

*C. Cauzzi, Dept. Structural Eng., Politecnico di Milano, Italy*
*C. Eva, Dip. Te. Ris., Università degli Studi di Genova, Italy*
*G. Ferretti, Dip. Te. Ris., Università degli Studi di Genova, Italy*
*V. Giraud, ARPA Piemonte, Italy*
*R. Paolucci, Dept. Structural Eng., Politecnico di Milano, Italy*

In the framework of the EC-funded Sismovalp project, dealing with the evaluation of seismic risk in Alpine valleys, the seismic response of Val Pellice, a fluvial –glacial valley located in North-Western Italy, Piemonte, has been analyzed. A temporary seismic network with several accelerometer and velocimeter stations was installed in the municipal area of Torre Pellice between June 2004 and March 2005, recording a large amount of weak earthquakes and teleseismic events. Local amplification of seismic waves is first investigated through H/V and SSR techniques. Subsequently, the empirical spectral ratios are compared with the transfer functions of 1D and 2D numerical simulations performed on two different cross-sections of the valley, derived from hybrid seismic profiles, down-hole and SASW tests. Finally, the applicability of the EC8 and of the Italian Seismic Code design spectra is discussed, to check whether the prescribed design spectral shapes can properly account for the 2D site amplification effects detected in the valley.

## SEISMIC MICROZONATION IN TWO VALLEYS OF THE EASTERN PYRENEES: ANDORRA AND LA CERDANA – ID 655

*A. Macau, Institut Cartogràfic de Catalunya, Spain*
*S. Figueras, Institut Cartogràfic de Catalunya, Spain*
*B. Colas, BRGM, France*
*B. Le Brun, previously at BRGM, France*
*A. Bitri, BRGM, France*
*T. Susagna, Institut Cartogràfic de Catalunya, Spain*
*J. Cirés, Institut Cartogràfic de Catalunya, Spain*
*M. González, CRECIT, Andorra*
*A. Roulle, BRGM, France*

Within the framework of the ISARD (Information of Seismic Automatic Regional Damage) project two valleys located in the eastern part of the Pyrenees, with different geological features, have been selected as pilot zones for the study of seismic risk. The Andorra la Vella - Escaldes – Engordany basin where most of buildings, infrastructures and economic activity of the country are concentrated, is characterized by a strong density of population. The Cerdanya Valley, located in French and Spanish territory, where the population distribution is spreader and is distributed in small urban nuclei. For the study of seismic risk two seismic scenarios have been chosen: for a return period of T=475 years and T=1975 years values of intensity VII and VIII and values of PGA 0,12g and 0,2g for both zones for average soil conditions have been obtained within the framework of the same project. Different approaches have been conducted in order to characterise the geological and geotechnical properties of the study area: use of geological maps, consulting reports from several geotechnical studies in the region, active seismic exploration to record Rayleigh wave for the SASW technique application to obtain shear velocity profiles and seismic noise measurements to obtain H/V spectral ratios. All this information allows us to constrain a realistic 1D soil columns to perform the computations of tranfer functions. Spectral ratios from accelerograms recorded in this area are also used. In Andorra, amplifications for frequencies higher than 1Hz are obtained, due to the thin sedimentary cover. In opposite, in the Cerdanya Valley the sediments that infill the basin, up to 800m thick, give rise to amplifications of the ground motion at smaller frequencies (<1Hz). The results of this study will be used, together with the building vulnerability assessment for the seismic risk estimation and the damage scenarios accomplishment.

## EFFECT OF DETONATIONS IN RURAL HOUSES OF THE SOUTH OF MEXICO – ID 694

*D. Murià-Vila, Instituto de Ingeniería, UNAM, Mexico*
*A. Escobar, Instituto de Ingeniería, UNAM, Mexico*
*E. Ovando-Shelley, Instituto de Ingeniería, UNAM, Mexico*
*J. Lermo, Instituto de Ingeniería, UNAM, Mexico*
*J. Hernández-Olazarán, PEMEX, Mexico*

Mexican petroleum company PEMEX, is making seismic prospecting tests in the south of Mexico. In this region, a great number of legal demands of the rural houses owners have been presented against PEMEX. Presumably, their houses were affected by the soil vibration due to the blasts carried out. So, the company requested an investigation with the purpose to know the values particle velocity limits for the typical houses of the region and to determine the possible causes of the reported damages of these houses.

In order to take care of this project, they identified the types and constructive practices of the houses (inspection of 300 houses) and the geotechnical and geophysical characteristics of the ground were determined in 34 sites of the region. Based in these works the structural response of 12 typical houses and of the surrounding soil were measured, under vibrations produced by the detonating weight of charge at the distance between 5 and 240 m and to 30 m depth of borehole. Two types of explosives with different weight of charge per borehole (1, 2.5 and 5 kg) were used.

The results of the field and laboratory tests allow to define the type and the magnitude of damage that can take place in the houses selected for this study. It was found that, the referred damage is explained essentially by deficiencies of the constructions and for the expansion and contraction effects of the soil. Also, the study allows propose a particle velocity limits in function of the frequency which takes into account the characteristics of the soils and the sensitivity of the rural housing of the region.

## SEISMIC MICROZONATION OF TLAXCALA CITY, MEXICO – ID 705

*J. Lermo, UNAM, Mexico*
*I. Bernal, UNAM, Mexico*

In order to make a regional seismotectonic analysis of the state of Tlaxcala (Mexico), 45 earthquakes (between 1994 and 2004, Md $< 4.0$) have been compiled. Almost 70% of this seismicity is associated to the structure known as Graben de Puebla. The seismotectonic characteristics allowed to make a seismic zonation consisting of a zone of high activity (I), one of medium (II) and one of low (III). The zone labeled I represents the greatest seismic hazard and also encompasses the most populated cities (Tlaxcala, Santa Ana Chiautempan, Contla and Apizaco). An estimation of site effects for Tlaxcala City was made with Nakamura technique, using microtremors records in 69 points. Results were validated with the one-dimensional method. Spatial distribution of dominant period (To) allowed to make a seismic microzonification. Three microzones were identified: I, with a To between 0.3 and 0.8 s; II, with a To between 0.1 to 0.3 s and III, without site effects. Microzone II is the most vulnerable to earthquakes since the mode of vibration of the ground may coincide with that of the buildings.

## SITE EFFECT AND SEISMIC VULNERABILITY OF THE ACATLAN CITY, MEXICO – ID 706

*D. Vega, UNAM, Mexico*
*J. Lermo, UNAM, Mexico*

Acatlán City is located in the south of State of Puebla and it's one of most damaged towns by large intermediate-depth, normal-faulting earthquakes in the subducted Cocos plate. An experimental work is shown in this paper for estimating the site effect and vulnerability of the town. An isoperiod map, some theoretical transfer functions and peak ground accelerations (for the 15th June, 1999 Tehuacán earthquake) were calculated for evaluating the site effect. In the other hand, a structural census was made in 438 buildings and we define three structural configurations as the most common in the city and their seismic response was calculated for two types of seismic demand. One class of vulnerability was assigned to each configuration based on the story drifts values. The results indicate that the construction techniques are deficient and this is the major problem in the structural behavior of the buildings in the Acatlán city.

### SITE CLASSIFICATION MAP FOR CENTRAL EUROPE – ID 711

*M. Nyst, Risk Management Solutions, Inc., United States*
*C. Williams, Risk Management Solutions, Inc., United States*
*L. Hall, Risk Management Solutions, Inc., United States*
*T. Onur, Risk Management Solutions, Inc., United States*

Historic earthquakes have demonstrated that the properties of geological materials beneath a site have a major influence on the amplitude and frequency content of ground shaking. Consideration of site conditions is therefore an important part of seismic hazard and risk assessment.

This study presents a high-resolution site classification for Central Europe for use in regional scale seismic hazard and risk assessment. Site classes are assigned based on the methodology developed by Wills et al. (2000) for California, which uses the relationship between geological material and the shear wave velocity of the upper 30 m (Vs30). The application of this methodology to central Europe is tested successfully using borehole data from a variety of Quaternary environments. Adjustments to the classification scheme are suggested to better account for the collisional nature of this tectonic setting.

### ON ESTIMATION OF SITE AMPLIFICATION FROM AMBIENT GROUND NOISE – ID 713

*E. Safak, USGS, United States*

Analysis of ambient ground noise is becoming an increasingly popular method to determine site amplification. Ambient noise represents the vibrations of the ground due to small excitations from various sources, such as the energy transmitted from the foundations of buildings vibrating under wind loads, energy transmitted by heavy machinery operating on the surface, vibrations generated by traffic loads, and microtremors.

In general, records of ambient ground noise have very low amplitudes and signal-to-noise ratios. Fourier-based standard methods that are commonly used to analyze seismic data are not appropriate to analyze ambient data because low signal-to-noise ratios can cause large errors in spectral analysis, particularly when analysis involves spectral ratios. However, ambient vibrations are always available and data can be collected continuously. In most cases, ambient records are stationary (i.e., their frequency and temporal characteristics do not change with time), and the record length can be made infinitely long. Also, since there are a large number of sources for noise and excitation, it can reasonable be assumed that both the noise and the excitation are wide-band random processes. These properties of ambient data make it possible to utilize advance stochastic techniques for data analysis, such as statistical signal processing, optimal filtering, and adaptive noise cancelling.

This paper first presents some examples of the types and magnitudes of errors of standard techniques that are currently used to determine site amplification from ambient ground noise. The paper then shows that the analysis of ambient ground noise is equivalent to extracting low amplitude sinusoids buried in noise. By using elementary concepts from the statistical signal processing and optimal filtering theories, the paper introduces several new techniques to analyze ambient noise. The superiority of the new methods over the Fourier-based methods is demonstrated by using real records of ground noise from urban areas.

### SITE RESPONSE ANALYSES BASED ON SITE SPECIFIC SOIL PROPERTIES USING GEOTECHNICAL AND GEOPHYSICAL TESTS – ID 747

*P. Anbazhagan, Indian Institute of Science, India*
*T. Sitharam, Indian Institute of Science, India*
*C. Divya, Indian Institute of Science, India*

The objective of this paper is to find the response of soil overburden for the maximum credible earthquake (MCE) at a site using geotechnical and geophysical investigations. The site is located at Hindustan Aeronautical Limited Bangalore, India. Deterministic seismic hazard analysis (DSHA) has been carried out by considering the seismotectonic map for Bangalore region, prepared by considering faults, lineaments and historic earthquake events in an area of 350km radius around Bangalore city. The MCE has thus been determined by seismotectonic parameters and regional attenuation relation. It is found that the MCE has a moment magnitude of 5.1 causing a PGA of 0.146g. Due to lack of existing ground motion data, synthetic ground motion for MCE at the selected site is generated using the model developed by Boore, considering regional seismotectonic parameters. The over burden soil thickness at the site varies from 4m to 15m. The general soil profile in this site is silty sand with fine content of 28% to 48% followed by sandy clay with Plasticity Index varying from 6% to 16% and followed by weathered rock. The field standard penetration test (SPT) "N" value varies from 2 to 71. Geophysical investigations have been carried out using Multichannel analysis of surface waves (MASW) method, both 1-D and 2-D. The range of shear wave velocity is 200m/sec to 1100m/sec. SHAKE2000 has been used, for the site response study by considering the ground motion data and geotechnical parameters to evaluate the response spectrum and amplification using both the field tests data separately. The response spectrum from the geotechnical investigations gives higher spectral acceleration when compared to the response spectrum from the geophysical investigations. High spectral acceleration may be attributed to presence of very large amount of fines. Dynamic properties obtained from SPT are high strain values as compared to MASW.

### ESTIMATING OF SHALLOW VELOCITY STRUCTURE BY INVERSION OF RECEIVER FUNCTION – ID 754

*A. Petukhin, Geo-Research Institute, Japan*
*K. Miyakoshi, Geo-Research Institute, Japan*

Since the pioneering work of Langston (1979) receiver function method is widely used to estimate Earth crust and mantle structure. But to apply it to the estimation of shallow crust structure (1-5 km depth) or depth of sedimentary layer, which are important for prediction of strong ground motions, someone need to calculate receiver function at high frequencies, 3-5 Hz. High-frequency seismic waves are strongly scattered and calculation of receiver function in most cases is impossible. To avoid this problem, we can use close earthquakes, e.g. aftershocks, or a deep subduction earthquakes. Another problem, which is general problem for the velocity structure inversions, is the trade-off between velocity in a layer and thickness of layer. To resolve this trade-off, we can apply constrains to velocity in the layer, e.g. based on the PS test in a neighboring borehole, and estimate only thickness of layer. We applied developed methodology to estimate shallow structures at the K-net sites in the region of M6.1, Yamaguchi 1997 Earthquake in Japan. Structure of layers were fixed according to the geological structure in the region, velocity at shallowest layer was fixed using data from K-net sites, velocity of deepest layer was fixed according to the crustal structure, velocities in the intermediate layers were constrained using PS test results at a neighboring borehole Kik-net sites that penetrate into the same geological layers. Then, receiver functions were inverted for velocity structure using Genetic Algorithm; propagator matrix algorithm of Kennett and Kerry (1979) was used to calculate theoretical receiver functions. To validate estimated velocity structures we calculated synthetic waveforms for each site, using the discrete wavenumber method, and compared them with the observed waveforms in frequency range 0.5 - 2Hz.

### SITE EFFECT INVESTIGATION BASED ON DATA OF LOCAL NETWORK OF SEISMIC OBSERVATIONS IN THE URBAN AREA – ID 755

*D. Melkov, Geophysical Center of Experimental Diagnostics, Russian Federation*
*A. Kharebov, Geophysical Center of Experimental Diagnostics, Russian Federation*

Vladikavkaz city is situated in the region of high seismic

hazard. There is a fault with Mmax=7.1 in the south part of the city. In 2004 first time in the North Caucasus there was formed local network of seismic observations on the urban territory. It consists of four modern digital stations. Seismic stations were located in buildings of similar type and functionality on sites with different soil conditions. It allows to investigate activity of faults and peculiarities of earthquakes on sites with different soil conditions. There was developed software for automatic data processing, data systematization, fast records search and some other operations (network operation analysis, events selection). Such data systematization allows not only searching records in database but also performing more complicated operations using SQL. One of such operations is event selection. From the database there were selected records of events registered by all the seismic stations. There was formed a data array for each station containing all the records (6000 samples length) and performed Fourier transform. Analysis of Fourier amplitude spectra has shown that soil conditions strongly influence on the spectral structure of vibrations. For more detailed analysis there were performed calculations of amplification functions and H/V spectral rations. In the absence of outcropping rock in the region, there was selected site with the most simple and seismically good soil conditions (gravel with the depth of 200 m). H/V-rations are calculated for event records and compared with amplification curves. Accordance of H/V spectral rations with amplification functions gives a possibility to estimate natural frequencies of the selected site. As a result of research, natural frequencies of the sites and intensity increments have been estimated.

## PARAMETRIC STUDY OF SLOPE'S EARTHQUAKE RESPONSE – ID 801

*A. Razmkhah, IAU-South Tehran Campus, Iran (Islamic Republic Of)*
*M. Kamalian, IIEES, Iran (Islamic Republic Of)*
*M. K. Jafari, IIEES, Iran (Islamic Republic Of)*
*A. Sadroaldini, IAU-Arak Campus, Iran (Islamic Republic Of)*

Nowadays, it is well established that local soil conditions and irregular surface topography can have a crucial influence on damage severity and its spatial distribution during strong earthquakes. Most research on topographic effects has far focused on ridges. Some of the procedures and concepts developed for the analysis of the ridges may also be extended to slopes. However, there are also significant differences between the response of slopes and the response of ridges simulated as homogeneous half-spaces; foremost are the semi-infinite nature of material in the horizontal direction behind the slope crest and the potential of soil amplification of the motions. This paper presents the results of an extensive parametric study of seismic responses of two-dimensional slopes to vertically propagating incident P- and SV- waves. Clear perspectives of the induced scattering and amplification patterns are given by investigation of time-domain and frequency-domain responses. It is shown that site geometry (e.g. slope angle), wave characteristics and material parameters are the key parameters governing the slope's response. Simple formula and tables are proposed for estimating the characteristic site period and the average amplification potential of slopes, which could be easily applied in site effect microzonation studies of topographic areas

## ROAD EMBANKMENTS UNDER EARTHQUAKES: FAILURE MECHANISMS AND CORRECTIVE MEASURES – ID 818

*S. López-Querol, University of Castilla La Mancha, Spain*
*R. Porras-Soriano, University of Castilla La Mancha, Spain*
*R. Blázquez, University of Castilla La Mancha, Spain*

Road embankments are geo-structures usually built with granular soils underlying an almost impervious pavement layer. After an earthquake, it is very common to find a typical failure consisting on longitudinal cracks running parallel to the axis of the road, but not exactly at the middle of it. This type of failure, due to liquefaction of the granular soil, can be explained by means of a numerical two phase algorithm based on coupled solid and fluid displacements, which has been previously validated by the authors. Such a procedure incorporates as constitutive equation of the soil the well known endochronic law, embodied within the framework of an inelastic Biot's model. The paper summarizes the constitutive law and the numerical code employed in this study, and gives an explanation for the type of road failure mentioned above. In addition, some corrective measures, concerning geometry improvements and changes of the properties of the granular material at specific embankment locations are explored, in order to obtain recommendations for the geotechnical design of roads at seismic sites.

## ATTENUATION AND VELOCITY STRUCTURE IN THE AREA OF POZZUOLI-SOLFATARA FOR THE SITE RESPONSE ESTIMATE – ID 824

*S. Petrosino, INGV - Osservatorio Vesuviano, Italy*
*P. Cusano, INGV - Osservatorio Vesuviano, Italy*
*G. Saccorotti, INGV - Osservatorio Vesuviano, Italy*
*D. Galluzzo, INGV - Osservatorio Vesuviano, Italy*
*E. Del Pezzo, INGV - Osservatorio Vesuviano, Italy*

The 1D shear-wave velocity model in the volcanic area of Pozzuoli-Solfatara is inferred using the dispersion properties of Rayleigh waves generated by artificial explosions and microtremor. The group-velocity dispersion curves are retrieved from application of the Multiple Filter Technique and Phase Matched Filter to recordings of air-gun sea shots. The dispersion curves indicate Rayleigh-wave fundamental-mode group velocities ranging from 0.8 to 0.6 km/sec over the 1-12 Hz band. Group velocity dispersion are also obtained from an autoregressive analysis, to compare the results with those inferred from the MF analysis. The ambient noise recorded at a dense array is analysed by using Aki's correlation technique and an extended version of this method. The obtained phase velocities range from 1.5 km/s to 0.3 km/s over the 1-8 Hz band. The group velocity dispersion curves are then inverted to infer the shallow shear-wave velocity model down to a depth of about 250 m, for the area of Pozzuoli-Solfatara. The attenuation study is performed by analysing the amplitude spectral decay of Rayleigh waves with the distance, in different frequency bands. The attenuation curve is then inverted to infer the shallow $Q\beta$ inverse model. Using the obtained velocity and attenuation model, the theoretical ground response to a vertically-incident SH wave is calculated, providing two amplification peaks centered at 2.1 and 5.4 Hz. The transfer function is compared with those obtained experimentally from the application of Nakamura's technique to microtremor data, artificial explosions and local earthquakes. Agreement among the transfer functions is observed only for the amplification peak of 5.4 Hz. Finally the peak ground acceleration for the whole Campi Flegrei caldera and locally for the Pozzuoli-Solfatara area is evaluated using two different methods (random vibration theory and ground motion generated from a Gaussian distribution), providing the PGA values of 0.04 g and 0.097 g, respectively.

## APPLICATION OF H/V FOURIER SPECTRAL RATIO FOR ANALYSIS OF SITE EFFECT ON ROCK SITES IN TAIWAN – ID 836

*V. Sokolov, Geophysical Institute of Karlsruhe University, Germany*
*C. H. Loh, Natinal Taiwan University, Taiwan*
*W. Y. Jean, National Center Research on Earthquake Engineering, Taiwan*

The frequency-dependent amplification for rock (Class B) sites was studied using earthquake ground-motion database collected in Taiwan during implementation of the Taiwan Strong Motion Instrumentation Program. The database used includes several hundred records from earthquakes of ML 4.8 – 7.3 occurred in 1993-2004. The characteristics of amplification were evaluated using the well-known technique of horizontal-to-vertical Fourier spectral ratio (H/V) of the S-wave phase (Lermo and Chavez-Garcia 1993). The study allows us to analyze peculiarities of rock sites

amplification in Northern and Eastern Taiwan and to compare the amplification with similar data obtained recently for other regions. It was suggested to divide the Class-B site amplification into four types based on frequency of maximum amplification and the shape of amplification function. Analysis of the H/V ratios can allow recognizing unusual effects in site amplification, such as influence of nearby building. The applicability of the technique was also checked for a few stiff and soft soil sites (Classes D and E).

### CORRELATION OF AMBIENT NOISE GROUND VULNERABILITY INDEX [KG] WITH DAMAGE IN THESSALONIKI (GREECE) – ID 843

*A. Panou, Aristotle University of Thessaloniki, Greece*
*N. Theodulidis, ITSAK, Greece*
*A. Savvaidis, ITSAK, Greece*
*Z. Roumelioti, Aristotle University of Thessaloniki, Greece*
*P. Dimitriou, ITSAK, Greece*
*P. Hatzidimitriou, Aristotle University of Thessaloniki, Greece*
*A. Kiratzi, Aristotle University of Thessaloniki, Greece*
*C. Papazachos, Aristotle University of Thessaloniki, Greece*

The earthquake of June 20, 1978, (M6.5) caused severe damage in the city of Thessaloniki (Northern Greece) and demonstrated the vulnerability of modern cities. An eight–storey reinforced-concrete building collapsed in the city center, 4000 buildings suffered serious damage and 47 people lost their lives. Although many studies have been conducted since the earthquake, detailed investigation of the damage potential is still needed for an effective preparedness and seismic risk mitigation against future earthquakes. In this study ambient noise measurements were performed at 350 sites in the metropolitan area of the city of Thessaloniki. Sampling intervals between measurement points was 150m in the downtown district of the city and about 500m elsewhere. The ambient noise horizontal-to-vertical spectral ratio (HVSR) for each site was calculated and the fundamental frequency (fo) and corresponding HVSR amplitude level (Ao) were estimated. Based on the fo, Ao values, the ground vulnerability index Kg-value (Nakamura, 1996) was also calculated. Contour maps of the fundamental frequency (fo), the amplitude level (Ao) and the Kg-value were compared with the observed detailed damage distribution induced by the 1978 earthquake. As a result, in the areas that heavy damage was observed, the fundamental frequency (fo) of the sites was generally lower while the corresponding HVSR amplitude level (Ao) and the Kg-value was higher that those exhibiting light damage. Furthermore, Kg-value demonstrates a better correlation with damage distribution compared to that of the HVSR amplitude level (Ao). The aforementioned results indicate that the ambient noise spectral ratio technique HVSR and its product, namely, ground vulnerability index Kg-value, can satisfactorily point out areas of higher seismic risk potential in the city of Thessaloniki.

### STUDY ON NON-LINEAR BEHAVIORS OF STRONG MOTIONS IN OJIYA DURING THE 2004 MID NIIGATA PREF. EQ, JAPAN – ID 859

*S. Fukumoto, Tokyo Soil Research Co., Ltd., Japan*
*H. Yamanaka, Tokyo Institute of Technology, Japan*

On 23 October 2004, the 2004 Mid Niigata Pref. earthquake (Mj=6.8) struck Mid Niigata Pref., central Japan. At this moment, three strong ground motion records had been registered at central Ojiya city, of which station located in and around 700 meters distance, Niigata Pref. Among of three recorded stations, K-NET, JMA and Suisen House, the maximum acceleration is realized as 1,308gal with EW component of K-NET station; NS component is 1,147gal, then, seismic intensity is 6.7. However, peak accelerations of Suisen House are 730gal and 808gal of NS, EW component, respectively, seismic intensity is summarized to 6.1. In order to clarify a difference of each peak ground motion and seismic intensity, we calculated 1-D seismic response analysis of each observation site considering with 300m in depth using PS well-logging data and deep S-wave profile inverted by microtremor array data in Ojiya city. Seismic response analysis of equivalent linear method was performed using DYNEQ with frequency dependant consideration. After several calculation, it is realized that predomination of linear behavior of K-NET station are approximately 0.2s period using fore-shock record, then, strong ground motions of main-shock are realized as 0.7s period predomination. With estimating non-linear performance, large accelerations are amplified by surface soils (soft clay and gravels) down to 10m in depth with large shear strain distribution ranging from 1% to 2%. Also, it is realized that deep solid layers ranging from 100m to 300m in depth with over 500m/s S-wave velocity behaved with a little non-linear characteristics.

### SEISMIC BEHAVIOR OF 2D TOPOGRAPHIC FEATURES IN TIME DOMAIN AT HIGH FREQUENCIES – ID 864

*A. Razmkhah, IAU-South Tehran Campus, Iran (Islamic Republic Of)*
*M. Kamalian, IIEES, Iran (Islamic Republic Of)*
*M. K. Jafari, IIEES, Iran (Islamic Republic Of)*
*H. Ali Elahi, IAU-Arak Campus, Iran (Islamic Republic Of)*

Recent observations of major seismic damages show the significance of the site effect on the seismic amplification. This paper will be evaluated the 2D site response parametric study of topographic features (semi-elliptical, semi-sinusoidal and trapezoidal shapes) in time domain at high frequencies. The soil material is considered linear elastic. The assumed input motion of Ricker type is considered as a SV plane wave which is applied vertically. Parametric study is performed using HYBRID program which is one of the comprehensive numerical 2D programs for Finite Element – Boundary Element modeling in a half space. The accuracy and capability of this program have been established in study of different site effects, using several numerical and analytical examples. Among the parameters affecting the seismic response of topographies, geometrical characteristics are studied in this research. The results are demonstrated in the form of normalized parameters as shape Ratio (the ratio of height to half width of the topography) and dimensionless frequency. Therefore the achievements of this study can be generalized and used for different geometries and input motions. The results of the parametric study show that in all studied geometries, interference of different distributed plane waves makes a very disturbed field of waves inside the topography, where separation of different waves is very difficult. Also, and based on 2D analysis, the 2D dimensionless predominant frequency is determined in which the amplification ratio is larger than 1.0 at all points of topography and they have similar phases Finally. Simplified relations between the 2D and 1D peak ground acceleration (PGA) based on shape ratio is proposed.

### SITE EFFECTS EVALUATION IN LORCA TOWN (MURCIA, SPAIN) APPLICABLE TO SEISMIC RISK MANAGEMENT – ID 867

*M. Navarro, University of Almeria, Spain*
*A. García, University of Almeria, Spain*
*F. Vidal, University of Granada, Spain*
*T. Enomoto, University of Kanagawa, Japan*
*F. Alcalá-García, University of Catalonia, Spain*
*F. Luzón, University of Almería, Spain*
*A. Pérez-Ruiz, University of Almería, Spain*
*T. Yamamoto, University of Kanagawa, Japan*
*E. Ocaña, University of Granada, Spain*
*I. Matsuda, University of Kanto-Gakuin, Japan*

Recent small and moderate destructive earthquakes on the Ibero-magrebian region have shown that the determination of seismic hazard, oriented to seismic risk management in urban areas, requires an investigation on the possibility of resonance in the dynamic behaviour of buildings and soils. The evaluation of local site effects in Lorca town (southeastern Spain) were carried out from geological and geomorphological survey, ambient vibration measurements and simultaneous strong motion records on different soil conditions. A classification of shallow geologic materials, according to their seismic amplification capacity, identifying the

nature of the materials was obtained. The Spatial Autocorrelation method (SPAC) was applied to ambient vibration array data and S-wave velocity models in different parts of the town were determined. Ambient vibration records were performed at 75 observation points and the distribution was arranged on the cross points of a grid of 150m x 150m dimensions and the Horizontal-to-Vertical Spectral Ratio was calculated The results show smallest values of predominant periods correspond to the north-west zone of the town, with values around 0.1 sec. The central and south zones of the town show a heterogeneous distribution of predominant periods with values ranging from 0.2 to 0.8 sec. These values are strongly related with local ground conditions. The evaluation of ground shaking features has been obtained by comparison simultaneous strong motion records on different soil conditions and a rock reference site. The results show an amplification factor 5 times in soft soil in relation to the reference site. Building vibration measurements, excited by ambient vibration, were recorded at 36 RC buildings (between 2 and 12 stories) to determine natural period and damping predictors in the range of small amplitudes. Finally, a probability map of expected resonance phenomena in Lorca town, for small and moderate destructive local earthquakes, has been obtained.

## SEISMIC SITE EFFECT ESTIMATION IN THE CITY OF RABAT – ID 905

*B. Said, CNRST, Morocco*
*J. Nacer, CNRST, Morocco*
*I. B. Aomar, CNRST, Morocco*
*B. Lahcen, EMI, Morocco*

This study is based on the sites survey carried out in the capital city of Morocco, Rabat. For this aim, we used the Nakamura's technique to characterize local geological conditions in terms of the dynamic response of soil during earthquakes. According to Nakamura, this technique allows determination of the fundamental period and the maximum amplification factor of the soil column by the recording of microtremors during few minutes. We applied the Nakamura's technique in the city of Rabat to get distribution maps of dominant periods and amplification factors assessed in more than 250 sites. In order to discuss the results of this study, we used available information in this zone about the surface lithological and topographic conditions at some measurement site. Finally, we established microzoning map of the city of Rabat based on contours of dominant periods. In general, the dominant periods are higher on the hills bordering the Bouregreg River. Both topography and thickness of soil may have contributed in these sites effects. The microzoning map established in this study, can be used by engineers and decision makers for urban and land use planning as well as a guide for the reduction of the seismic vulnerability of buildings.

## LARGE VRANCEA INTERMEDIATE-DEPTH EARTHQUAKES AND SITE EFFECTS IN BUCHAREST URBAN AREA – ID 911

*N. Mandrescu, National Institute for Earth Physics, Romania*
*M. Radulian, National Institute for Earth Physics, Romania*
*G. Marmureanu, National Institute for Earth Physics, Romania*

The major earthquake that occurred in Vrancea region in March 4, 1977 (Mw=7.4) produced the collapse of 32 high-tall buildings in the central part of the Bucharest city, and other several tens of tall buildings were hard damaged. It was generally assumed that the main cause of this damage was the proximity of the building period of oscillation to the fundamental period of resonance specific for the geological conditions beneath the city. The main purpose of our study is to analyze the influence of the local natural conditions upon the soil response in Bucharest, in case of large (M>7) subcrustal Vrancea earthquakes. To this purpose, we use geological, geotechnical and geophysical information, including in situ measurements of shear wave velocities. The results of our study concerning site response evaluation, using the impedance contrasts and amplification factors, outline two main features of high significance for earthquake engineering practice: (1) inadequacy for the Bucharest city case of the standard procedure that limits the investigation depth in order to set soil dynamic characteristics to uppermost 30m; the local response during the large Vrancea earthquake is controlled by the entire package of Quaternary cohesionless deposits which are significantly thicker than 30m beneath Bucharest and (2) difficulty to delineate zones with different local amplifications; thus, for Bucharest urban area and strong subcrustal Vrancea earthquakes one can refer rather to regional effects than "local effects".

## INELASTIC SEISMIC RESPONSE OF SOIL DEPOSITS – ID 919

*V. Drosos, National Technical University of Athens, Greece*
*N. Gerolymos, National Technical University of Athens, Greece*
*G. Gazetas, National Technical University of Athens, Greece*

Many constitutive models and numerical codes have been proposed for non-linear seismic response of soil. However, the difficulty in calibration of the model parameters prevents the wide use of these models. In this paper, a simple but efficient numerical code for the calculation of the non-linear one-dimensional seismic response of multi-layered soil profiles is presented. The code is based on the phenomenological constitutive model BWGG developed by Gerolymos & Gazetas (2004) as an extension of the Bouc-Wen model. After properly calibrating its parameters, the model describes with realism the time-domain non-linear hysteretic behavior of plethora of materials. Emphasis is given on the calibration procedure and the verification of the code. Parameters calibration is accomplished using: (a) the well documented and widely used soil stiffness versus strain (G–$\gamma$) and damping versus strain ($\xi$–$\gamma$) curves of literature, and (b) results from other established numerical codes of the one-dimensional seismic response analysis. The potential of generalized use of the calibrated parameters is verified through comparison of the proposed code results with experimental results from the literature. Data from centrifuge tests, shaking table experiments, and in-situ (vertical arrays) records is utilized for this goal. The good comparison of the calculated results with the experimental ones gives confidence in use of this new numerical tool for the non-linear seismic response analysis of soil deposits. It is revealed also that the equivalent-linear method tends to overestimate the soil response even under moderate excitations and therefore the necessity for inelastic analysis is inevitable.

## SEISMIC RESPONSES OF GROUNDS AND VIADUCTS IN ZONE OF DERAILMENT OF SHINKANSEN BULLET TRAINS – ID 1051

*S. Mori, Ehime University, Japan*
*S. Kazuni, Ehime University, Japan*

Shinkansen bullet trains were derailed during Niigata-ken Chuetsu earthquake, October 23, 2004 with a magnitude of 6.8. The purpose of this paper is to estimate the seismic responses of the grounds and viaducts in the zone of the derailment for studying the possible cause of the derailment by dynamic analysis using simplified models verified by microtremor array measurement on grounds and viaducts. One-dimensional models of ground for seismic response analysis are developed at 17 sites based on soil profiles with SPT data. Equivalent linear analysis is conducted using program SHAKE. Linear models of single-degree-of-freedom systems for viaducts at ten sites are developed based on microtremor measurement on grounds and viaducts. The results of analysis show that values in a range of alluvial terrace are larger than those in a range of alluvial fan with regard to responses of acceleration of the grounds and viaducts. Based on witnesses of crew, it is clearly shown that the trains ran through the zone of the beginning of derailment, which corresponds to the range of alluvial terrace, in the time range of occurrence of maximum acceleration responses. The maximum value of horizontal acceleration response of viaduct is estimated to be over 1,600 cm/s2, which equals to 70 % of critical acceleration for derailment. Nonlinear amplification of ground motion on alluvial terrace and correspondence of timing between occurrence of maximum acceleration of ground motion and running of bullet trains at the beginning point of the derailment seems to play important role in the derailment.

### INFLUENCE OF "LONG-TERM TIME" EFFECTS ON THE SOIL STIFFNESS IN LOCAL SEISMIC RESPONSE EVALUATION – ID 1107

*C. Madiai, University of Florence, Italy*
*G. Simoni, University of Florence, Italy*
*G. Vannucchi, University of Florence, Italy*

It is widely known that in laboratory tests the dynamic shear moduli at low shearing strain amplitudes increase with time of confinement and also at higher shearing strains soils exhibit a "long-term time" effect. This effect could play an important role on soil dynamic behaviour and it should be properly accounted when interpreting laboratory moduli to determine in situ soil stiffness for engineering practical applications. The aim of this research is to analyse the influence of the "long-term time" effect on the local seismic response. The study was developed on an area of Northern Italy where eluvial-colluvium and post-glacial lacustrine deposits of known age are present. An experimental testing program including three Down-Hole tests and several laboratory tests on indisturbed samples was conducted by the Geotechnical Laboratory of the Department of Civil Engineering of the University of Florence to assess static and dynamic properties of the two formations. In the paper the results of field and laboratory tests for characterization of three soil profiles are presented. 1-D local seismic response analyses of the three sites was also shown by comparing the results obtained taking into account the "long-term time" effects with those estimated neglecting them.

### INFLUENCE OF SITE EFFECT IN DAMAGE STATE OF FRAMED STRUCTURES SUBJECTED TO EARTHQUAKE – ID 1155

*S. Klarica, University of Los Andes, Venezuela*
*B. Vera, University of Los Andes, Venezuela*
*J. Flórez-López, University of Los Andes, Venezuela*

One of the main goals of earthquake engineering is the prediction of the behavior of soils, when they are overload by seismic events, and its influence on the response of civil engineering structures. Geological conditions of local site can produce amplification of seismic waves that will results in important material damages and sometimes tragic loss of life. This phenomenon is well known as seismic site effect. In order to improve earthquake mitigation strategies, it seems very important to quantify acceleration and damage amplification due to soil movement in active seismic areas. All the simulations presented in this paper show the interaction between soil and structure. The soil properties correspond to the geological data of the city of Mérida, Venezuela, which is on an important active seismic fault. The structural response is based on a damage model developed at the University of Los Andes in Venezuela. This damage model combines the plastic hinge concept with fracture mechanics and continuum damage theory. The simulations measure the influence of site effect on the state of damage in framed structures. The model was included in a commercial structural analysis program, called ABAQUS, as a new finite element. Soil was represented using the conventional finite elements included in the library of the program. The fault was represented as a discontinuity with unilateral contact conditions in the soil mesh. The earthquakes are generated numerically by the application of shear forces on the lips of the fault. A parametric study is carried out through the variation of the mesh dimensions and materials properties. Structural configuration was also modified. All the results describe the seismic response of soils and the structure; and point out the amplification of the seismic waves and the influence of site effect on various levels of damage of framed structures subjected to earthquakes.

### A COMPARATIVE STUDY OF THREE METHODS FOR ESTIMATION OF SITE EFFECTS – ID 1158

*S. Ólafsson, University of Iceland, Iceland*
*R. Sigbjörnsson, University of Iceland, Iceland*

In the study that is reported here three different methods are applied to estimate site effects using accelerometric strong-motion data. The objective of this study is to compare the methods, assess their validity and reliability, the purpose of which is to improve models for estimating strong ground motion. The acceleration data used in the study is from earthquakes in South-Iceland Seismic Zone that is available on the Internet Site for European Strong-motion Data (ISESD). At some of the sites records are available from several events. Limited prior studies have been made of site effects in Iceland. This is the first study that is made using all the available strong ground acceleration records. The three methods applied to the accelerograms are: (1) the Nakamura method (H/V method); (2) the method of separating the site effects from source and path effects by means of non-linear optimisation (sometimes called generalized inversion technique) and (3) finally fitting a parametric model representing vertically propagating S-waves. The site response parameters are computed using these three methods and results compared. The predominant period of ground motion and the amplitude of the main spectral peak can be used for classification of site effects. Incomplete geological and geophysical data exist for the strong-motion stations as well as the area. Based on this limited information and parameters estimated from the accelerograms a classification of site effect is made with respect to the site classes proposed by NHERP and Eurocode 8.

### ALTERNATIVE METHOD FOR COMPUTATION OF UNIFORM HAZARD SPECTRA WITH SOIL EFFECTS – ID 1170

*A. Perez, Unam, Mexico*
*M. Ordaz, Unam, Mexico*

The objective of this work is to show an alternative method to compute uniform-hazard spectra at soft soils. The method uses random vibration theory to compute a power spectral density function (PSDF) compatible with the uniform hazard spectrum at rock, and a transfer function that could be obtained by analytical or empirical methods. The spectra determined in this way are approximately equal to the uniform hazard spectra computed with rigorous methods, but the numerical effort is of orders of magnitude less than the required by the latter. The proposed method is developed in four steps: 1) determination of the appropriate duration of the intense phase of motion; 2) computation of the PSDF associated to the uniform hazard rock spectrum (input) 3) computation of the transfer function for the site using the PSDF computed for the rock spectrum; 4) calculus of the uniform hazard spectra with soil effects (output) by means of random vibration theory and the convolution of the PSDF of rock spectrum and the transfer function.

Some application examples are presented and the advantages and limitations are explored and commented.

### STRONG MOTION AND NOISE ANALYSIS AT TOLMEZZO-AMBIESTA DAM SITE (NE ITALY) – ID 1234

*C. Barnaba, OGS-CRS, Italy*
*E. Priolo, OGS-CRS, Italy*
*A. Vuan, OGS-CRS, Italy*

During the May 6, 1976 Friuli earthquake in Italy (MW 6.4), the ENEA-ENEL accelerometric station of Tolmezzo-Ambiesta dam (TLM1) recorded acceleration peaks of 0.358 g and 0.268 g on the horizontal and vertical components. These are among the highest peak accelerations measured in Europe and have been largely used in the past into empirical attenuation relations. There is the doubt that the high peak values recorded might be strongly influenced by local site effects and by dam nearness. The goal of this study is to estimate the spectral amplification of the Tolmezzo-Ambiesta dam accelerometric site, to determine the possible factors that influence such an amplification, and to re-evaluate the ground motion recorded during the 1976 main shock by filtering out the local site contribution. In order to investigate and quantify the spectral response of the TLM1 station, a spectral analysis on 1976 Friuli earthquakes is carried out, using different

techniques. Noise measurements are also performed around the accelerometric station (the hill where the station is located, the dam nearby, and the surrounding relieves) to infer their natural frequencies. Three distinct resonant frequency bands are recognized by analysing Friuli 1976-77 earthquakes: 1) at 1.8 – 2Hz, 2) at 3.8 – 4Hz and 3) at 6 – 8Hz. The higher frequency bands at 3.8 – 4Hz and at 6-8Hz are related with the natural frequencies of the dam (first and higher modes), while the lower frequency amplification at 1.8-2.2Hz can be interpreted as the resonance of the 800m high south-western relief where the dam is stuck. Finally, the original record of the 1976 main shock is filtered out by the site effects and a "site-free" acceleration peak value is estimated. The filtered PGA values are about 30% lower than that measured at the Ambiesta dam site.

### NUMERICAL COMPUTATION OF PROBABILITY DENSITY FUNCTIONS FOR MULTI-DIMENSIONAL STOCHASTIC PROBLEMS – ID 1276

*G. Faschingbauer, Institute for Construction Informatics, Germany*
*R. J. Scherer, Institut for Construction Informatics, Germany*

A method to compute the discrete probability distribution of the resonant frequencies of stratified soil with several layers over half-space will be proposed and conclusions for further development are drawn. The stochastic description of the resonance behavior of layered media is of particular interest in various engineering disciplines, e.g. earthquake engineering, geotechnical engineering, acoustics. In engineering practice this kind of problem is dealt with Monte Carlo Simulation which is applicable for almost all problems, if a deterministic solution of the problem – either analytical or numerical – is well-known. Nevertheless, simulation methods need a large number of realizations in order to deliver appropriate results. Especially for the computation of very low probabilities the Crude Monte Carlo Simulation (CMCS) reaches its limits. Therefore a new method, called Discrete Random Variable Method (DRVM), will be proposed in this contribution. This method is based on discretisation of the random space, combination of these discrete random variables and numerical computation of the corresponding probabilities. For simple deterministic models, the results of the first rough algorithm have shown good results. Disadvantage of the current algorithm is the computational expense for higher dimensionality of the random space. Nevertheless, the method has high potential for further development and improvement. Envisaged improvements of the method are (1) accelerated computation of the resonant frequencies by inductive learning methods, (2) adjustment of the increment of discretisation of the random variables according to the sensitivity to the resonant frequency and (3) an advanced algorithm for the computation of the combinations of discrete variables based on vector and matrices oriented programming techniques. Because the generation of the samples is not subject to randomness, very sensitive ranges of the resonant frequency can be considered systematically. This contribution will show the basic concept of the method and the possibilities for further development by methods of computer sciences.

### DETERMINATION OF VS PROFILE OF DEPOSITS IN BAM CITY USING ONE-POINT MICROTREMOR MEASUREMENTS – ID 1282

*A. Kavand, University of Tehran, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*

Site effect has been known as the major cause of large ground amplifications during several recent catastrophic earthquakes. Consequently, the evaluation of site effect is an important factor that must be considered in mitigation of earthquake hazards. Shear wave velocity is a key parameter that controls dynamic response of a site. Hence its profile must be identified down to the seismic bedrock. Generally geotechnical or even geophysical methods are expensive and time consuming for this purpose. As an economical and simple substitute, microtremor measurements can be used. In order to investigate the reliability of Vs profiling by using microtremors, a series of microtremor measurements have been conducted in Bam city (southeast of Iran) that experienced the damaging earthquake of December 2003. Microtremor measurements included 49 one-point observations distributed over the city. Based on the H/V spectrum of microtremors, shear wave velocity profiles were determined at the measurement sites using nonlinear inverse analyses. Ultimately reliability of the method was investigated, comparing results of microtremor measurements and seismic reflection and down-hole methods.

### EVALUATION OF SITE EFFECTS ON STRONG MOTION DATA BY MEANS OF MICROTREMOR MEASUREMENTS – ID 1285

*A. Kavand, University of Tehran, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*

Southeastern regions of Iran (Bam, Zarand) have experienced two destructive earthquakes recently. The main shocks of the earthquakes were recorded by many digital accelerographs (BHRC) in several stations at the region. A series of microtremor measurements have been conducted in earthquake record stations. In this study H/V spectrums of microtremor data are obtained and compared with that of strong motion data. Comparisons are done on both predominant site period and amplification ratio. The results show that microtremor measurements are promising in determination of site period but not in amplification ratio. By deconvolution of earthquake records at the ground surface, the records are obtained in bedrock and then site response analyses are done to obtain ground motion in Bam city. For this purpose soil layer profiles are taken from some available geotechnical logs in the city or from inversion of microtremor data.

### THE EFFECTS OF LOCAL SITE CLASSES ON THE DYNAMIC BEHAVIOR OF ELEVATED TANKS – ID 1313

*R. Livaoglu, Karadeniz Technical University, Turkey*
*A. Dogangun, Karadeniz Technical University, Turkey*

This study aims, firstly, to give a synthesis work related to the dynamic behavior of elevated tanks in different soil conditions defined by two different codes. For this purpose two different supporting systems as a circular frame and a cylindrical shell system are considered for sample elevated tanks. Modal Analysis Method is used for seismic analysis. Four local site classes for the Turkish Earthquake Code (TEC-98) and four local site classes for Eurocode-8 (EC-8) are used in the seismic analysis. The results of the elevated tanks for both supporting systems in the local site classes are compared each other. Some conclusions and discussion related to effects of local site classes on the dynamic behavior of elevated tanks drawn from this study are given at the end of the study.

### DETERMINATION OF SITE EFFECTS BY AMBIENT VIBRATION MONITORING – ID 1320

*H. Wenzel, VCE, Austria*

Site effects may increase the response beyond the provisions of local Codes or Standards. Measurements that determine these effects can be of help to get the correct design input values and save considerable money in critical zones.

The introduction of EC8 has brought considerable changes in the risk assessment in countries north of the Alps. In previous so called quiet zones earthquake is now the guiding design factor. For the huge stock of existing structures the assessment of a realistic risk becomes essential and economically important.

The paper will describe the SEISMID method which stands for Seismic System Identification. Based on an artificial micro earthquake created by a defined falling weight, the response of the surrounding soil as well as the structures is monitored. Several sophis-

ticated methodologies are combined in order to generate a valid risk map for the region as well as for very local circumstances. The results are microzonation for the city, which is of interest to the community, as well as detailed assessment of structures, which is of interest to the owners.

A number of examples is available for demonstration. The quality of prediction will be discussed and compared to conventional approaches.

### A FIRST APPROACH TO THE ESTIMATION OF SITE EFFECTS IN THE CITY OF OSLO (NORWAY) USING THE NAKAMURA (H/V SPECTRAL RATIO) TECHNIQUE – ID 1415

*P. Conde, Dpto. Ciencias de la Tierra y del Medio Ambiente, Spain*
*S. Molina, Dpto. Ciencias de la Tierra y del Medio Ambiente, Spain*
*C. Lindholm, NORSAR, Norway*

A wide understanding of site effects is highly important in order to estimate and to prevent the damage due to earthquakes in the most of the urban areas. When damaging earthquakes happen, often the closest areas to the epicenter are not the places with a higher level of damage and human losses. Sometimes, the soil characteristics below the city are responsibles for wave amplification, liquefaction, etc. and these effects provoke the collapse of many buildings and the death of numerous people. The city of Oslo (Norway), is placed on a soft soil basin with known depths of approximately 100m in some sites. Although the current seismicity is of moderate to low size, it has a record of historical earthquake which where highly felt in the city, causing some damage and frightening the population. Also, the 1989 Western Norway earthquake (M=5.2) was widely felt in the city of Oslo, approximately 300 km from the epicentre. The main goal of this investigation is to carry out a first approach to the microzonation of the city using the Nakamura technique (H/V spectral ratio). Using velocity sensors, more than 20 records of ambient noise were taken across the city, which were processed using the Nakamura technique. As main results a map of predominant frequencies has been obtained and by also using known depths of the sediments it has been possible to establish a frequency-depth relation for the area. Finally, using these results the mean shear wave velocity in the sediments of the city was computed with a value of aproximately 200 m/s, which agrees with independent measurements. The results of this work are preliminary and the authors intend to improve the study with more noise measurement using low frequency sensors.

### MAIN LEARNINGS FROM THE ESG2006 BENCHMARKS – ID 1428

*P. Y. Bard, LGIT, France*
*C. Cornou, LGIT, France*
*E. Chaljub, LGIT, France*

Following the ESG tradition, the Third International Symposium on Effects of Surface geology, to be held in Grenoble from August 30 to September 1, 2006, has been an opportunity to orgnize two benchmarks in order to better assess our present capability a) to predict ground motion parameters for a given scenario earthquake within a specific 3D basin structure, and b) to derive reliable information on site velocity profile from array microtremor measurements. The presentation will first briefly recall the structure and contents of the two benchmarks, as detailed on http://esg2006.obs.ujf-grenoble.fr), then present the techniques used by the various particpating teams (between 15 and 20 for each benchmark), and will finally outline the main learnings of the comparisons between prediction results. While it is obviously too early to anticipate the outcome of this comparison in the present abstract, it is however possible to identify some topics for such a comparison : · Is there a coupling between surface topography and basin effects ? · Do model predictions agree up to intermediate frequency range (3-4 Hz) when they deal with the same scenario event and the same propagation medium ? · What is the dependence of computed site amplification factors on source location and magnitude, in case of short epicentral distances ? · What is the variability range of soil velocity profiles estimated from the same microtremor array data ? Is this variability reduced when the same processing technique and software is used by different teams ? · Is this variability mainly associated with the derivation of surface wave dispersion curves, or form their inversion ? · What is the actual confidence level of S-wave estimates, and its depth dependence ?

### RAPID SCREENING OF SITE EFFECTS THROUGH MICROTREMOR SURVEYS IN VIEW OF MICROZONATION STUDIES – ID 1431

*H. Cadet, LGIT/LCPC/CETE, France*
*P. Y. Bard, LGIT/LCPC, France*
*C. Cornou, LGIT/IRD, France*
*P. Gueguen, LGIT/LCPC, France*

Effects of site conditions on seismic ground motion have been well recognized, with dramatic consequences on damages distribution. Accounting for site effects in seismic regulation has thus gained increasing importance in earthquake risk reduction programs, but “non standard” site effects are not well accounted for in regulation. Given the alpine geological setting of the area, the site amplification is mainly associated with recent (often post-glacial) deposits in valleys and possibly topographic amplifications. The objective of this study is to rapidly screen a large area with simple and low cost methods, in order to identify the main zones where specific site conditions are expected to cause large amplification effects, which would justify local microzonation studies. Emphasis is thus put on the development of a methodology allowing to identify places where large 2D or 3D effects are expected: this is done through the combined analysis of the H/V frequency, shear profiles estimated only within the surficial layers and the width-to-thickness ratio of the valley. After having performed a first selection of sites on the basis of a regional geological map and location of urban centers, for being efficient in the field campaign, we propose to first carry out H/V measurements in order to estimate the main geometrical characteristics of the site (1D, 2D or 3D); then for the selected sites to derive the S-wave velocity at shallow depth through an appropriate array geometry. A series of abacus were developped in that aim for circular array geometry (6 sensors). The subsequent crossing of this information with the regional hazard level, and the vulnerability allowed to propose to local authorities a priority ranking for microzonation studies. This procedure will be detailed for one particular example (Port-Saint-Gervais, Isère valley), and final results will be presented for 12 sites.

### ACCOUNTING FOR EPISTEMIC UNCERTAINTIES IN SITE EFFECT STUDIES: EXAMPLES OF A LOGIC TREE APPROACH – ID 1432

*P. Y. Bard, LGIT, France*
*D. Fäh, ETHZ, Switzerland*
*A. Pecker, Géodynamique et Structure, France*
*J. Studer, Studer Engineering, Switzerland*
*N. Abrahamson, PG&E, United States*

Probabilistic estimates for site specific studies are most often separated into "regional" PSHA to estimate the rock spectra, and local analysis to derive the site amplification factors: this latter part is mainly deterministic and is applied to the rock spectra corresponding to the design return period. This presentation will focus on several developments achieved recently within the framework of the PEGASOS project to account for site effects in a fully probabilistic way, including both epistemic uncertainties and aleatory variabilities. This approach was based on a wide spectrum of computations using different 1D soil columns to account for the uncertainty of soil parameters, different input spectra to account for non-linear effects, and various modelling approaches (1D/2D, various incident wave fields, without / with close sources). The final uncertainty is estimated through a logic tree approach: not only the weights for each branch do vary from one expert to another, but also the structure of the logic tree itself. Some examples will be given and briefly discussed. Some examples of resulting median amplification curves, together with their variability and sensitivity

to the level to input ground motion, will be shown. The effects on the final hazard curves are significant: while obviously frequency dependent, they also strongly depend on the return period because of non-linear effects : significant amplification at low return periods may be replaced by attenuation at much longer return periods, so that the shape of the hazard curves may be significantly modified with respect to rock hazard curves. This first experience brought several additional very valuable methodological learnings that will be briefly discussed.

### SHALLOW GEOLOGICAL STRUCTURE PROPERTIES USING HVSR AND COMPARISON WITH OTHER GEOPHYSICAL INFORMATION – ID 1531

*I. Papadopoulos, Technological Educational Institute of Crete, Greece*
*A. Savvaidis, ITSAK, Greece*
*N. Theodoulidis, ITSAK, Greece*
*C. Papazahos, AUTH, Greece*
*F. Vallianatos, Technological Educational Institute of Crete, Greece*

A detailed study of the shallow geological structure in the city of Chania, (Crete Island, Greece) has been conducted using available geophysical methods. Results from Nakamura's Horizontal-to-Vertical Spectral Ratio [HVSR] method for single station microtremors analysis and ambient noise array recordings have been mainly used and compared with independent information derived from electrical resistivity and seismic refraction, seismic velocity measurements in boreholes and borehole data in order to obtain information about the geophysical and geological structure of the area under investigation. Approximately 100 single station ambient noise recordings were carried out, covering almost the whole urban area of the city of Chania, using a 5-sec period seismometer. Array noise recordings using broadband seismometers were also carried out at ten sites of different geological formations in order to evaluate the Vs profile down to the depth of the bedrock. Shallow electrical resistivity and seismic refraction tomographies were conducted wherever possible, in order to obtain information about the boundaries of the upper layers of the subsurface. All the previous information was combined with available borehole and geophysical data in order to provide detailed information about the geological structure down to a depth of 300 m. The results of this study show that the city of Chania is laying over a complex 3-D geological structure, mainly comprised of marly limestone as bedrock, overlaid by marles and quaternary deposits. In general, most sites have shown significant amplification at quite low frequencies (<1 Hz). The depth of the interface between the sediments and the bedrock on the basis of the shear wave velocity using array noise recordings has been estimated to vary between 40 and 120 m depth. Results were compared with previous studies in the same area (Athanassopoulos, 2000, Mastrolorentzo, 2004), showing a rather good agreement with respect to shear-wave velocities and resonance frequencies.

### SITE CHARACTERIZATION BY INTELLIGENT SYNTHESIS OF EARTHQUAKE RECORDS, CASE STUDY ON 2003 BAM TREMOR – ID 1536

*M. Safi, Power & Water University of Tehcnology, Iran (Islamic Republic Of)*
*M. Tehranizadeh, AmirKabir University of Tehcnology, Iran (Islamic Republic Of)*

A new method is proposed for determination of soil type in the region lacking site investigation reports. This method benefits advantages of artificial intelligence in classification problems. Using this method the ranges of shear wave velocity for each soil type are estimated for a large data base of Iran ground motion records. This site classification has been performed using linear acceleration response spectra of the records. It has been shown that the method can characterize some site parameters very fast and with acceptable accuracy. The method has been applied to December 26, 2003 Bam Earthquake in Iran. The strong ground motion, effective time duration and damage assessment of this disaster has also been briefly discussed in this paper. The effects of earthquake magnitude and epicentral distance on the classification results have also been presented.

### MICROZONATION STUDIES BASED ON GEOPHYSICAL DATA IN BUYUKÇEKMECE (ISTANBUL) REGION – ID 1574

*S. Karabulut, Istanbul University, Turkey*
*U. Ceyhan, Istanbul University, Turkey*
*I. Osmansahin, Istanbul University, Turkey*
*F. Ozcep, Istanbul University, Turkey*
*H. Alp, Istanbul University, Turkey*
*O. Gundogdu, Istanbul University, Turkey*

Study area is located in Büyükçekmece (Istanbul) which is one of the districts of Istanbul city and placed at the shore of the Marmara Sea as an earthquake prone area especially after the destructive earthquakes in 1999. For microzonation purposes, seismic refraction measurements, microtremor measurements, borehole and laboratory data carried out in Buyukcekmece (Istanbul,Turkey) area. For the study area, relative amplifications, liquefaction safety factors, site characteristic periods and soil classifactions has been determinited. According to the site characteristic period map, period values are between 0,1-1,36 and 0.3-0.6 seconds by seismic refraction and microtremors, respectively. Relative amplifications are between 1.4-3.6 and 1.0-3.4 values by seismic refraction and microtremors, respectively in this area. Liquefaction Safety Factors and Liquefaction Potential parameters in some sites are respectively smaller than 0,8 value. The main purpose of this study is mapping of the predominant period, relative amplifications and liquefaction safety factors by using microtremor observations and seismic refraction measurements for the area of Büyükcekmece Soil classification map (NEHRP), site characteristic period map, amplification maps, liquefaction safety maps have been prepared.

### SITE SPECIFIC SPECTRAL AMPLIFICATION AT ADDIS ABABA – ID 1588

*G. B. Yoseph, IIT Delhi, India*
*G. V. Ramana, IIT Delhi, India*

In this study the sensitivity of free field peak ground motion has been analyzed considering uncertainties in (i) thickness of soil layers, (ii) dynamic material properties such as shear wave velocity, modulus reduction and damping behavior and (iii) peak ground acceleration (pga) on the rock outcrop. Soil properties and earthquake hazard scenarios in Addis Ababa city where insufficient data is available is used as case study. Five earthquake magnitudes 6.4, 6.7, 7.0, 7.3, 7.6 and epicenteral distances of 25, 50, 80, 100, 120, 150km were considered that are in conformity with earthquake activities for the region and Kijko's method of maximum earthquake magnitude determination. The soil column at the particular site was subjected to ground motion history generated at rock outcrop using specific barrier model. The thickness of unconsolidated material, pga, shear wave velocity, modulus reduction and damping properties were treated as random variables and geotechnical properties available along the proposed ring road site investigations were used to characterize the necessary parameters. The sensitivity of site specific spectral amplification for variability of the above entities was numerically analyzed by using equivalent linear analysis software. The results indicated that spectral amplification is controlled predominantly by dynamic material properties and relatively insensitive to the variability of pga of the bedrock.

Keywords: dynamic soil properties, soil amplification, response spectra

### AN ANALYTICAL SIMULATION OF THE SEISMIC FIELD WITH MEMORY PHENOMENA – ID 1614

*Z. Tuaeva, Geophysical Center of Experimental Diagnostic, Russian Federation*

An analytical simulation of the seismic field is repre-

sented for non-uniform layer. Dynamics of elastic medium is well known only for linear models of environment. The submitted model takes into account nonlinearity of the heterogeneous medium for which the macroscopic condition at present time depends on their condition during earlier moments of time. This phenomenon refers to as memory of medium. The phenomenon of memory is submitted as the certain law. The purpose of research - to study the response of such medium. The 3-D wave-field is characterized by the displacement vector that satisfies the Navier-Cauchy equation of motion with the initial and boundary conditions, and the stress T is related to the displacement gradient by the Hooke's law for isotropic elastic medium. Method of linearization is used. The integral equation for the zero-order approximation is obtained and solved (approximation by iteration). The resulting diagram of analytical simulation is well represented.

### WHAT IS THE POTENTIAL SEISMIC RESPONSE OF THE GENEVA TROUGH ? – ID 1617

*S. Hurter, University of Geneva - CERG, Switzerland*
*C. Frischknecht, University of Geneva - CERG, Switzerland*

The study area is located in the Geneva basin which forms the south-western part of the Swiss Plateau and occupies a depression surrounded by reliefs: the first chain of the Jura Mountains in the North, the Vuache in the South-West and the Salève ridge in the South-East.

This part of Switzerland is characterized by a low seismic activity but owns a high potential seismic risk. Indeed this canton is highly populated and industrialized. It is therefore necessary to evaluate the seismic response so as to take measurements necessary to the protection of the people and the goods.

Historical and recent earthquakes that occurred in Switzerland and in surrounding countries (e.g. Epagny 15.07.96, MW 4.6; Vosges 22.02.03, ML 5,4 and Doubs 23.02.04, MW 4,6) showed that Geneva can be affected and that seismic response differs depending on Geneva soil conditions.

On a geological point of view, the canton of Geneva is entirely built on a Molasse basin, which is mostly overlain by fluvio-glacial and lacustre deposits. The Geneva geological service assigned seven classes of specific soil conditions. One of the most intriguing is the class D, characterized by more than 30 meters of unconsolidated fine sands, silt and clays and located in a trough caused by glaciers. The exposed part of this structure is around 110 meters deep, 9 km long and 1,2 km wide. Consequently one of the questions to be resolved is what kind of seismic response this trough is susceptible of.

Therefore, this investigation focuses on this particular zone. Due to the low level of seismic activity, preliminary seismic site analysis is carried out using the H/V ratio on seismic ambient noise at various sites along this trough.

### TOWARDS AN INTEGRATED METHODOLOGY FOR SITE EFFECTS ESTIMATION – ID 1690

*F. Barazza, Università di Udine, Italy*
*R. Carniel, Università di Udine, Italy*
*P. Cesario, Università di Udine, Italy*
*E. Del Pin, Università di Udine, Italy*
*M. Di Cecca, Università di Udine, Italy*
*E. Fabris, Università di Udine, Italy*
*S. Grimaz, Università di Udine, Italy*
*P. Malisan, Università di Udine, Italy*
*E. Puntel, Università di Udine, Italy*
*M. Riuscetti, Università di Udine, Italy*
*M. Lorenzo, Universita di Udine, Italy*

Most of the techniques for estimating shallow shear velocities for assessment of site response are usually expensive and/or logistically complex, especially in noisy urban settings. In this work we present the combined use of techniques characterized by cheapness and limited logistical requirements. The well known Nakamura method is based on the H/V spectral ratio of ambient noise recordings. The determined peak frequencies are interpreted as the fundamental resonance frequencies of the investigated sites, thus providing information on shallow layers characteristics and geometry. In order to better highlight these resonance frequencies, we make use of time series analysis techniques such as Singular Spectrum Analysis, Wavelet Transforms and Empirical Mode Decomposition. The general idea is to maximize the 'matching' between the spectral ratios along the two horizontal directions. The seismic noise can also be processed by the so called ReMi (Refraction Microtremor - SeisOpt® ReMi$^{TM}$) technique aimed at deriving a shear velocity profile through the use of an interactive Rayleigh-wave dispersion modeling tool. The slowness-frequency wavefield transformation is here the crucial step in optimizing the inversion in the present of urban incoherent noise. In this presentation we focus our attention on the optimization of each technique, also from a methodological point of view, and on the problem of combining the results provided by each algorithm in a coherent way, possibly incorporating additional information coming from localized, more detailed information such as refraction seismic or borehole data that may be available to constrain the modelling. In particular, ReMi-derived stratigraphies are used as a starting point in a Shake-based interactive modelling environment that is then optimized in order to better compare to the Nakamura derived resonance frequencies, finally producing also an estimate of the amplification factors that cannot be derived from the Nakamura method alone.

### SITE AMPLIFICATION FACTOR ASSESSMENT VIA A MULTIDISCIPLINARY APPROACH: AN APPLICATION IN MOLISE REGION (SOUTHERN ITALY) – ID 1716

*S. Barani, Dip.Te.Ris.-University of Genoa, Italy*
*R. De Ferrari, Dip.Te.Ris.-University of Genoa, Italy*
*G. Ferretti, Dip.Te.Ris.-University of Genoa, Italy*
*C. Eva, Dip.Te.Ris.-University of Genoa, Italy*
*D. Spallarossa, Dip.Te.Ris.-University of Genoa, Italy*

The application of both 1D/2D numerical simulations and spectral techniques applied to experimental data leads to reliable and accurate site response estimates in different geological and topographic conditions. This work deals with the evaluation of site amplification effects in order to define microzonation maps of four Molise municipalities (Southern Italy) shocked by the 2002 seismic sequence (Magnitude of the mainshock, which occurred in October 31, 2002, Ml = 5.4). The ground response analysis is conducted following a multi-step procedure that consists of (1) collecting geologic, geomorphologic, geothecnical and geophysical data (in order to characterize seismo-stratigraphical units and define simplified geological sections), (2) evaluating reference response spectra by means of conventional probabilistic seismic hazard analysis (PSHA)and defining the seismic input as the most appropriate suite of real accelerograms by means of PSHA disaggregation, and (3) evaluating the site response through 1D/2D numerical simulations. The procedure is first applied to Ripabottoni village for which H/V ratios of both microtremor data (Nakamura technique) and earthquake recordings, and RSM (Reference Site Method) site response estimates allow the validation of the transfer functions computed by numerical simulations. Such procedure is then applied to the other three municipalities. The results, cast in terms of resonance frequencies, response spectra, and amplification factors, generally show moderate local amplification effects due to low seismic impendance contrasts between the bedrock and the overlying soils. However, areas characterized by particular morphostratigraphical features, such as landslide bodies, high weathering deposits and topographic irregularities, are affected by large amplification phenomena.

### LONG-PERIOD STRONG GROUND MOTIONS IN TOMAKOMAI, THE YUFUTSU BASIN, HOKKAIDO DURING THE 2003 TOKACHI-OKI, JAPAN, EARTHQUAKE – ID 1718

*K. Hatayama, National Research Institute of Fire and Disaster, Japan*

We successfully reproduced some important features of large-amplitude long-period (6.5 to 15 s) strong ground motions

observed in the Yufutsu basin, Hokkaido, Japan during the 2003 Tokachi-oki, Japan, earthquake (Mw8.0) by numerical simulations of wave propagation and found the effective factors in underground structures that controlled those features. The recordings from the Japanese dense nation-wide strong-ground-motion networks demonstrated the strong spatial variation of long-period motions inside the Yufutsu basin and revealed that the long-period shaking in the Tomakomai western port was the strongest among all other areas inside the basin. In the Tomakomai western port, some of large oil storage tanks suffered such serious damage as fires and sinking of floating-roofs by liquid sloshing. To study how this observational feature can be explained using the available underground structure data, we simulated the propagation of the 2-D wave-field, assuming the underground models derived from microtremor array measurements in the Yufutsu basin [Kanno et al.(2005)]. Our calculated waveforms well agree with the observed ones. The features of the underground model assumed here are that the bedrock with an S-wave velocity over 3 km/s decreases its depth to about 4 km around the Tomakomai western port, while its depth increases down to 6 km where long-period ground motions had less amplitudes than those of the Tomakomai western port. On the other hand, the low-velocity sedimentary layers existing close to the ground surface become the thickest around the Tomakomai western port. We therefore recognized that the shallow underground structure (< 1 km) rather than the bedrock depth contributed to the excitation of the strongest long-period (6.5 to 15 s) ground motions in the Tomakomai western port. These findings suggest that we should be careful to the detailed underground structure including the shallow part as well for accurate prediction of long-period strong ground motions.

## SCATTERED WAVES INDUCED BY IRREGULAR TOPOGRAPHY – ID 1735

*H. Mogi, Saitama University, Japan*
*H. Kawakami, Saitama University, Japan*

It has been pointed out that the ground with an irregular surface causes complicated seismic responses. However, the process of generating these complex responses is not yet clarified. In this study, this process in two-dimensional SH-wave field was investigated. Firstly, we examined the mathematical expression of scattered-wave contribution, and it was pointed out that the mathematical expression of the scattered-wave contribution has a form similar to that obtained from the Huygens–Fresnel principle consisting of a wave function and an inclination factor. Next, numerical analyses were conducted for the ground having a sinusoidal-shaped irregular surface. In these analyses the time-domain responses of the ground surface and the waveforms of the scattered-wave contributions were evaluated. The comparison between them showed that the complicated shapes of the responses are caused by the arrivals of the scattered waves. The waveforms of the responses can be explained in terms of the first-order scattered-wave contributions, since they dominate over the higher-order contributions. Finally, the first-order scattered-wave contributions were closely examined based on the aforementioned mathematical expression, and the following conclusions were drawn: (1) The polarity of the first-order scattered wave in time-domain is attributed to the inclination factor. (2) At the bottom of a valley, the scattered waves generated at its nearby surface dominate because of the short distance from the source of scattered waves. These scattered waves appear nearly at the same time of arrival of the incident wave and always reduce the amplitude of the incident wave due to their negative polarity. (3) On the contrary, at the peak of a hill the scattered waves generated at the nearby surface have positive polarity, and they always enhance the response. (4) At the flank no significant scattered waves are generated at the nearby surface because of the rectilinear shape of the surface.

## NONLINEAR SEISMOLOGY. THE QUANTITATIVE DATA – ID 1745

*G. Marmureanu, National Institute for Earth Physics, Romania*
*C. Cioflan, National Institute for Earth Physics, Romania*
*A. Marmureanu, National Institute for Earth Physics, Romania*

The model of linear elastic response of the Earth has been almost universally used by seismolgists to model teleseismic,weak,and also strong earthquakes.For teleseismic and weak ground motions,there is no reason to doubt that this model is accepted.Laboratory tests consistently show the reduction in shear modulus(G) and increase in damping ratio(D) with increasing shear strain(g);G=G(g),respectively,D=D(g), therefore nonlinear viscoelastic constitutive laws are required.Aki wrote:„Nonlinear amplification at sediments sites appears to be more pervasive than seismologists used to think...Any attempt at seismic zonation must take into account the local site condition and this nonlinear amplification" (Aki,A., Tectonophysics,218,pp.93-111,1993).The seismological detection of the nonlinear site effects requires a simultaneous understanding of the effects of earthquake source,propagation path and local geological site conditions. The authors,in order to make evidence of large nonlinear effects, introduced the spectral amplification factor (SAF) as ratio between,for example, maximum spectral absolute acceleration and peak values of acceleration(a-max),from processed strong motion record. If we hold the same (SAF)=5.8942 for the relatively big earthquake from 1990 May 31, having magnitude MGR=6.1 (the response considered by us in the elastic domain), acceleration should be in the same station, for the 1990, 30 May the acceleration should be (a*)max=0.1540 cm/s2 (+14.16%), but the recorded value was just amax=0.135 cm/s2. Also, for the 1986, August 30, (MGR=7.0), the maximum acceleration should be (a*)max=0.107 cm/s2 (+45.57%) compared to the recorded value of 0.0736 cm/s2 recorded at the same Bacau station. The authors are coming with new quatitative data which will open up a new challenge for seismologists studying nonlinear site effects in 2-D and 3-D irregular geological structures,leading them to a fascinating research subject in nonlinear physics"(Aki,p.108,idem).

## COMPARISON OF SITE RESPONSES TO AMBIENT NOISE, WEAK AND STRONG GROUND MOTION – ID 1826

*P. Dimitriu, ITSAK, Greece*
*N. Theodulidis, ITSAK, Greece*

An increasing number of studies use ambient-noise measurements to characterise site response, for example by means of the H/V (horizontal-to-vertical) spectral-ratio method. It has been established that this approach can yield accurate estimates of the site's fundamental-resonance frequency (the estimates of the amplification level are generally unreliable). The question addressed here is whether these estimates can be used to model site response during strong ground shaking, e.g. during earthquakes. To this end we investigated the response of five soft sediment sites in Greece (NEHRP classes D and C) to strong (>10%g) and weak (<10%g) earthquake motions, and compared the earthquake H/V ratios with ratios obtained from ambient noise recordings at the corresponding sites. Our results indicate that site-response characteristics revealed by noise recordings may differ from those displayed in earthquake data. Thus, ambient noise may sometimes fail to show the fundamental-resonance peak (less frequently this may happen with earthquake recordings). And when noise data do reveal the fundamental-resonance peak, at soft-sediment sites its frequency will be overestimated relative to the strong-motion one owing to soil nonlinearity.

## THE IMPACT OF HYDROGEOLOGY ON EARTHQUAKE GROUND MOTION IN SOFT SOILS – ID 1876

*D. Hannich, University of Karlsruhe, Germany*
*H. Hoetzl, University of Karlsruhe, Germany*
*D. Ehret, University of Karlsruhe, Germany*
*G. Huber, University of Karlsruhe, Germany*
*M. Bretotean, National Institute of Hydrology, Romania*
*A. Danchiv, University of Bucharest, Romania*
*V. Ciugudean, METROUL S.A., Romania*

The multiple influences of shallow aquifers on the earthquake ground motion and the site amplification are studied in

the case of the city of Bucharest, the capital of Romania, since 2002 within the German-Romanian joint research program "Strong Earthquakes – a Challenge for Geosciences and Civil Engineering". This program was initiated in 1996 by the Collaborative Research Center 461 (CRC-461) at the University of Karlsruhe and is financed by the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG). The hydrogeological influences are analysed as shear wave velocity variations within sandy and gravely layers as well as modifications of the liquefaction potential in correlation with site- and time-dependent variations of the groundwater level. Quasi-simultaneous groundwater level measurements at more than 230 sites covering the whole city area of Bucharest were performed and serve as basis for the assessment of areas with confined and unconfined state of the groundwater as well as for the elaboration of a groundwater flow model. A 3D groundwater flow model with forecasting features for the shallowest upper aquifer in Bucharest is in elaboration, to make possible the estimation of the groundwater level at the moment of a future earthquake. Recently performed Seismic Cone Penetration Tests (SCPTu) offer new results concerning values for the shear wave velocity in the upper 30 m, with special regard for unsaturated and saturated sandy layers. The cyclic resistance ratio (CRR) of the penetrated soil layers, necessary for the calculation of the factor of safety against liquefaction and of the index of liquefaction probability, is also deduced from the SCPTU-measurements. Pressure gauges for pore-water pressure and earth pressure records during earthquakes were installed at two sites in Bucharest within shallow silty-sandy and sandy-gravely layers. Thus the triggering mechanism of liquefaction through increasing respectively excess pore water pressure during earthquakes in liquefaction-prone sandy layers in Bucharest is studied.

## SITE RESPONSE CHARACTERIZATION OF THE FLORENCE URBAN AREA (ITALY) USING SEISMIC NOISE MEASUREMENTS – ID 1895

*V. D'Amico, Dept. Earth Sciences, University of Siena, Italy*
*D. Albarello, Dept. Earth Sciences, University of Siena, Italy*
*F. Baliva, Dept. Earth Sciences, University of Siena, Italy*
*M. Picozzi, Dept. Earth Sciences, University of Siena, Italy*
*F. Agili, Dept. Earth Sciences, University of Firenze, Italy*

We present the results of a study aiming at the geostructural and seismic characterization of the subsoil of the city of Florence through passive seismic techniques. To this purpose, ambient noise was registered and analysed through the HVSR single-station technique to supply estimates of the fundamental resonance frequency of soft soil. A wide survey of seismic noise measurements was conduced at more than 150 sites in order to identify the occurrence of significant resonance effects and to assess lateral changes of the 1D site response over the study area. In addition, at a number of sites, noise was registered on bidimensional arrays to constrain the local S-wave velocity profiles for the shallower subsoil (up to 50-100 m depth). The joint analysis of the results coming from the two surveys allowed a first-order reconstruction of the basin underground geometry, which has been then compared with information available from a great number of stratigraphic log data.

## SEISMIC MICROZONATION OF BUCHAREST: NUMERICAL MODELLING OF SITE EFFECTS – ID 1911

*D. Ehret, Karlsruhe University, Dept. of Applied Geology, Germany*
*G. Huber, Institute for Rock and Soil Mechanics, Germany*
*D. Hannich, Karlsruhe University, Dept. of Applied Geology, Germany*
*V. Osinov, Institute of Geotechnical Engineering, Austria*

Bucharest belongs to Europe's cities with the highest seismic risk. The seismicity is caused by the rupture of the subduced East-European plate in the south-eastern part of the Carpathians. During the 20th century four major earthquakes (Mw = 6.9 – 7.7) occurred in this 80 – 200 km deep seismogenic volume. The epicentral region of these earthquakes is confined to the Vrancea region, a 30 km wide and 70 km long area about 160 km north of Bucharest.

In order to elaborate building codes for earthquake-endangered cities it is very important to know the local site effects. They can be investigated either directly by measuring response spectra for many sites or indirectly by calculating response spectra based on a geological model. The first approach has the disadvantage that in most cases measurement results exist only for weak motion and not for the more relevant strong earthquakes. On the other hand, if enough geological and geotechnical data are already available (which applies to the most modern cities), the latter approach enables to calculate the response spectra both for weak motion and for strong motion by using constitutive laws, that take as well non-linearity into account.

In the first step a 3D geological and hydrogeological subsurface model of Bucharest was developed. To investigate shear wave velocity, density and other geotechnical properties Vertical Seismic Profile- (VSP-), Seismic Piezocone Penetration Test- (SCPTu-) and special seismic Crosshole-measurements have been performed. Subsequently, the ground response was calculated at each of these sites using synthetic signals. For the modelling the (visco-) hypoplastic constitutive law was used. After validation of the modelling results the ground response will be calculated and interpolated for the entire city area to produce a microzonation map.

This work is being carried out within the German Collaborative Research Center 461: "Strong Earthquakes: A Challenge for Geosciences and Civil Engineering".

## GRAVIMETRIC AND MICROSEISMIC CHARACTERIZATION OF THE GEMONA (NE ITALY) ALLUVIAL FAN FOR SITE EFFECTS ESTIMATION – ID 1935

*E. Furlanetto, University of Trieste - Dip. Scienze della Terra, Italy*
*G. Costa, University of Trieste - Dip. Scienze della Terra, Italy*
*F. Palmieri, OGS, Italy*
*A. Delise, University of Trieste - Dip. Scienze della Terra, Italy*
*P. Suhadolc, University of Trieste - Dip. Scienze della Terra, Italy*

The urban area of Gemona (NE Italy) is mainly built on alluvial fan sediments that contributed to the destruction of the city during the Friuli earthquake, May-September 1976. Three accelerometric stations of the Friuli Venezia Giulia Accelerometric Network, run by the Department of Earth Sciences, University of Trieste, in collaboration with the Civil Defence of FVG, are set in Gemona for site effects estimation purposes. Using weak motion recordings of these stations, we are able to derive the H/V spectral ratio and also to apply the reference site technique. The result of these elaborations shows different resonant frequencies in the two sites (one on the fan, one on the sedimentary basin), when excited by the same event, and also different resonance frequencies at the same site when excited by different events. This can be explained with 2D or 3D site effects modelling, that requires, however, the characterization of the local subsoil structures, in particular the sediment-bedrock contact. We use gravimetric data to characterize a model with a homogeneous sedimentary layer of variable thickness along five selected profiles. The models are elaborated using the residual Bouguer anomaly and, as a constraint, three boreholes that reach the bedrock, geological outcrops and intersection points on the profiles. We derive the mean thickness along all the profiles and the bedrock undulations. We validate the modelling using a second approach based on seismic noise data acquired along the same profiles. The data are analysed to calculate the fundamental frequency of soft soil using Nakamura's techniques, that is compared to resonance frequencies calculated from weak motion events. The lack of agreement confirms the 2D or 3D character of the alluvial fan. However, the computed thickness of sediments along all the profiles match the ones determined from gravimetric inversion results.

## ROBUST TECHNIQUE FOR SITE-EFFECT EVALUATION – ID 1973

*V. Pinsky, Geophysical Institute of Israel, Israel*
*Y. Zaslavsky, Geophysical Institute of Israel, Israel*

Usual approach to estimate site-effect from microtremor

measurements is to compute spectral ratio of horizontal-to-vertical components H/V (Nakamura's technique). The main problem of this method is a large scatter of H/V ratio maximum amplitudes and a somewhat less scatter of corresponding frequencies. This instability of the estimates is related apparently to non-stationarity of the microtremor sources randomly distributed in time and space. We interpret the H/V ratio in terms of the transfer function of a linear dynamic system (LDS) with input V and output H observed with non-stationary and correlated noise. Consequently the problem of accurate site effect estimation is determined by selection of the sequence of time windows with relatively large input and output Signal-to-Noise ratio. However, we have no means to compute SNR from observations but it is possible to judge about it indirectly. For this purpose we estimate maximal amplitudes and corresponding frequencies of H/V ratio in a sequence of time windows and then collect time windows were the data is clustering around certain frequencies and amplitudes. Then we continue sorting the data fitting best to the assumption of the 1D LDS model described by a vector of parameters. The outliers in the new parameter space are automatically removed by a sort of clusterization procedure based on the statistical robust Maximum-likelihood approach (M-estimates), thus providing relatively more stable maximum amplitude and frequency estimations. Such approaches make it possible to assist the routine analyst processing but doesn't exclude intelligent interpretation using apriory knowledge about geological and velocity undersurface structure. The interactive and automatic procedures, using this principal have been designed and verified on a number of simulated and real data, showing good performance.

### RESPONSE OF THE ALLUVIUM IN THE LIMA-PERU AREA – ID 1983

*D. Huaco Oviedo, Regional Center for Seismology for South America, Peru*

To determine the site response in Lima-Peru the spectral ratio method for small earthquakes has been applied, theoretically the method is restricted to similar wave paths for the site and for the basement rock, but for the case of Lima, which has an area of 50 x 50 km, the distance between the site and the basement may reach the order of epicentral distance, so it is not possible to have only one point as the reference on the basement rock. The average thickness of the alluvial is of 400m. The response of Mayorazgo (MYZ), a site on the alluvial has been explored comparing the two sites on the basement, Nana (NNA) and La Molina (LMO). The transfer functions show that, between the frequency range from 1 Hz to 20 Hz, the spectral ratio MYZ/NNA and MYZ/LMO are similar, opening the possibility that for Lima it is possible to use several outcrop rocks as the basement rocks in order to obtain the amplification factors.

The relative amplification factor of the alluvial of the central part of Lima has also been determined. Three earthquakes have been used recorded by strong motion instruments at Lima (PQR) and in Zarate (ZAR), Surco (SCO), La Molina (MOL), one event in each station. For the destructive earthquake 10-03-74, 7.5 Ms, the spectral ratio between SCO/PQR/ is oscillatory; it is not possible to identify any amplification range. For the strongest aftershock 11-09-74, 6.2Ms the ratio MOL/PQR, the amplification is of the order of 3 between 1 to 10 Hz. La Molina was the locality most affected by the main shock. Finally the ratio ZAR/PQR shows amplifications greeter than one.

### ESTIMATION OF SITE EFFECTS IN THE AREA OF THE SOUTH OF THE UPPER RHINE GRABEN: SEISMIC MICROZONATION BY USING AMBIENT NOISE MEASUREMENTS AND CALCULATION OF AN ATTENUATION MODEL – ID 1984

*V. Calbini, IPGS, France*
*M. Granet, IPGS, France*

The studied area is located close to the border between France, Switzerland and Germany, in the South of the Upper Rhine Graben (URG). The URG is characterized by a low to moderate seismicity with some significant earthquakes both at historical and recent times. The region is also characterized by densely populated areas and sensitive industries. The URG is characterized by a thick layer of tertiary sediments with a depth of basement ranging from 1200m to 3500m. It is now well known that this kind of geological and geometrical configuration can lead to the existence of site effects. In order to estimate them, we used the classical Nakamura's method. 250 seismic noise measurements were made on a 1km x 1km grid size. These measurements coupled with local geological and geotechnical soil information lead to a microzonation map. The first conclusion is that the fundamental frequency is quasi constant (between 0.8Hz and 1.2Hz) in the whole area. It corresponds to an impedance contrast at about 100m depth probably caused by a transition between sandstones and marls. To complete this study, we build different attenuation models using 500 earthquakes recordings for which the local magnitude (Ml) is greater than 3. For each model, different kinds of parameters were tested (distance, site, PGA). These empirical models are the first step of the attenuation modelling. Indeed, due to the moderate seismicity level of the region, the use of semi-empirical laws will be more relevant

### UNCERTAINTIES ESTIMATION IN SITE-SPECIFIC 1D AND 2D LINEAR AND NONLINEAR WAVE PROPAGATION FOR PSHA STUDIES – ID 2011

*L. F. Bonilla, Institut de Radioprotection et de Surete Nucleaire, France*
*P. C. Liu, Institute for Crustal Studies, United States*
*S. Nielsen, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

The new worldwide building codes propose design response spectra based on probabilistic seismic hazard analysis (PSHA). The resulting uniform hazard spectra (UHS) are usually computed for rock sites. However, in the case of site-specific studies, local site effects need to be taken into account. Nonetheless, numerous problems arise from the fact that we have a limited knowledge about the mechanical properties of the medium. In addition, we also have an inherent uncertainty related to the different seismic sources capable of producing the expected ground motion at the site. Furthermore, the resulting UHS come with their uncertainty estimates usually from logic tree analysis. This implies the need to compute the local site conditions effects from more than a single estimate of the average medium model. Indeed, we need to estimate the UHS on sediment with their corresponding confidence levels. In the following study we use a logic tree analysis, similar to those used in standard PSHA studies, to propagate the uncertainties of the source (acceleration time histories) and the mechanical properties of the sediments (random media). We first explore the full combination of models using 1D linear and nonlinear wave propagation. Then, from the analysis of the resulting confidence limits we go back to the models than can be used in 2D wave propagation. In this way we reduce the time of the needed computation for such larger models. Furthermore, we use a simple deaggregation procedure to study which parameters control the most the uncertainty on the soil local amplification. An example of application will be shown for the Grenoble basin in France

### SITE CLASSIFICATION AND AMPLIFICATION IN THE MISSISSIPPI EMBAYMENT FOR REGIONAL SEISMIC RISK ESTIMATIONS – ID 2025

*T. Onur, Risk Management Solutions, Inc, United States*
*L. Hall, Risk Management Solutions, Inc, United States*
*G. Molas, Risk Management Solutions, Inc, United States*

Regional site response studies typically use a simplified method to the estimation of site amplification such as a NEHRP-like approach wherein site classes are assigned to various geological units (based on surficial units and subsurface stratigraphy when available). Amplification factors are then determined for short-period and long-period response of each of these site classes. However, deep sedimentary basins provide an added complexity to the regional site response estimations, since the depth of the soft sediments needs to be incorporated into this framework. Mississippi Embayment (ME) in the New Madrid Seismic Zone (NMSZ) is an example, where the depth of the sediments reaches about 1000m.

The city of Memphis, TN, which is the largest urban center in the area, is relatively close to the NMSZ (less than 100 km to the closest fault segment), and is located near the middle of the upper ME. As part of a larger regional seismic risk project for Eastern North America (United States and Canada), we investigate the distribution of surface and subsurface geology in the ME, and its potential for amplifying the earthquake ground motions. Site classes are assigned using the relationship between geological material and the average shear wave velocity of the upper 30 m (Vs30). This follows methodologies developed for California, although adjustments are made to ensure consistency with measured Vs30 observations in the ME and surrounding region. There are two major site classes in the ME, commonly called "Uplands" and "Lowlands" units. For these, the effect of the sediment depth was incorporated into the development of amplification factors by linking the sediment depth to site periods obtained through analytical and experimental studies.

### ASSESSMENT OF SEISMIC SITE AMPLIFICATION AND SEISMIC BUILDING VULNERABILITY IN REPUBLIC OF MACEDONIA – ID 2029

*Z. Milutinovic, IZIIS-Skopje, Macedonia*
*G. Trendafiloski, IZIIS-Skopje, Macedonia*

The Nakamura's H/V method is world-widely used technique for estimation of dynamic characteristics of surface soil deposits and characterization of building dynamic characteristics. A project "Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the Macedonia, Croatia and Slovenia" has recently been launched under the auspices of NATO Science for Peace Program (NATO SfP 980857). It is performed by 3 academic institutions from the above listed countries (Institute of Earthquake Engineering and Engineering Seismology /IZIIS-Skopje/, University "Ss. Cyril and Methodius", Skopje, Macedonia; Department of Geophysics, Faculty of Science, University of Zagreb, Croatia; Environmental Agency of the Republic of Slovenia - Seismology Office, Ljubljana, Slovenia) and coordinated by Department of Structures, Soil Mechanics and Engineering Geology, University of Basilicata and Department of Earth Sciences, University of Siena, both from Italy. The project in itself promotes a new integrated method and technology for "fast" seismic microzoning and seismic vulnerability assessment of buildings with wide application possibilities in particular for identification of locations with potential resonant characteristics and thus, the increased seismic risk for buildings. Within the national part of the NATO SfP 980857, IZIIS plans to perform measurements of more then 100 high-rise (7+ stories) buildings. Ambient and microtremors measurements of 28 high-rise building and corresponding free field sites have already been completed. The measured buildings are typified, twelve stories RC skeleton tower-type buildings erected following the catastrophic 1963 Skopje earthquake in accordance with the 1964 Seismic Design Code of former Yugoslavia. The results showed negligible variation between the measured predominant periods, demonstrating the uniform quality of the construction, however significant differences between the measured and analytically calculated predominant periods due to neglecting of stiffness of nonstructural elements in analytical calculations.

## CS6: Early Warning, Shaking and Loss Scenarios

Level-1

### SEISMIC DAMAGE MAPS FOR DISASTER MANAGEMENT USE IN URBAN AREAS IN DEVELOPING COUNTRIES – ID 119

*F. Nateghielahi, AZAD U. SOUTH, Iran (Islamic Republic Of)*
*R. Nematolahi, ERC-TEHRAN, Iran (Islamic Republic Of)*

There exist many cities in developing countries which are built with minimal seismic considerations. Also, due to the expenses associated with the detailed and analytical identification of such vulnerable buildings and structures in these cities, it seems that a rapid and inexpensive solution for assessment of a general understanding of the vulnerability of such cities is required for disaster management planning purposes. In this regards, in this study, a simplified evaluation form was developed in order to assess the key seismic vulnerability parameters of the buildings and the structures in city of Yasuj located along the southern sections of the Zagrous mountain range in Iran. Based on the gathered data, a data bank was created and by using the generalized physical vulnerability functions, developed for typical Iranian buildings, a series of scenario base damage maps for the city was established. Using these maps, and available resources in the city, a series of disaster management planning maps were generated for different levels of the potential earthquake hazard. These simplified and cost effective procedures used for the city of Yasuj, has established the preliminary needs for disaster planning while more sophisticated methods are being explored. In this paper, method used will be discussed and results obtained will be presented. It is believed, this simple data management and mapping can be utilized in similar cases especially in developing countries where financial and technical experties are limited.

### PRELIMINARY EVALUATION OF SEISMIC RISK IN KISHINEV CITY – ID 259

*V. Alcaz, Institute of Geophysics and Geology, Moldova, Republic Of*
*A. Zaicenco, Institute of Geophysics and Geology, Moldova, Republic Of*
*E. Isiciko, Institute of Geophysics and Geology, Moldova, Republic Of*

A PC-based methodology has been developed in order to facilitate the process of designing programs to manage urban seismic risk and rescue operations in the Republic of Moldova. The application evaluates damages to built facilities and casualties from scenario or real earthquake in conditions of the limited time and initial information. The probability of damage suffered by the structures for given level of seismic hazard is evaluated using response spectra or macroseismic intensity. The central part of Kishinev (2.5x2.5km test site), capital of the Republic of Moldova, is the test area of the project aimed on the assessment of vulnerability of buildings to seismic impact. This city is exposed to the influence of earthquakes from Vrancea area; mean peak ground accelerations from attenuation relations for medium soil conditions PGA=2,0m/s2 for recurrence interval T=475yr. Introduction and classification in ArcView GIS format of the main dynamic characteristics of the subsoil: shear wave velocities, amplification factors, together with designing the database for the existing structures were performed. The final product is the software with GIS interface capable to perform fast assessment of scenario seismic events, evaluate seismic damage to facilities and mapping of ground motion parameters: PGA, EPA, etc. Generally, the damages of buildings and human casualties on the territory of Moldova Republic must be assessed taking into account at least: i) directivity effects; ii) local soil conditions and iii) vulnerability of the existing building stock. The results of computations based on proposed methodology are: 1)expected values of macroseismic intensity in each country district; 2)expected values of PGA; 3)expected structural damage; 4)expected number of casualties. In order to assess the efficiency of the offered system the comparison of predicted damage-loss for two of strong earthquakes of the XX century (1940, M=7.4 and 1986, M=7.0 years) with real observed was carried out.

### EVALUATION OF RISK COMPONENTS FOR THE CITY OF ISTANBUL – ID 269

*S. Kundak, Istanbul Technical University, Turkey*
*H. Dulger Turkoglu, Istanbul Technical University, Turkey*

Earthquakes can give great damages to urban areas according to their intensity and the vulnerability level of settlements. In general terms, the value of earthquake risk depends on the

severity of hazard and the vulnerability of the elements which will be affected. Istanbul faced several earthquakes such as it had experienced in 1509, 1799 and 1894. According to the recent scientific researches, in the next 30 year period, another major earthquake will likely occur and will cause vast damages in Istanbul. This study aims to reveal the factor loadings of risk components according to the different risk levels in Istanbul. In this study, a detailed data based was constructed including natural, built environmental, demographic and economic aspects of the city which cover 613 neighborhoods of 23 districts of Istanbul. According to the results of principal component analysis used in this research, the independent variables explain about 67,3% of the total variance and form 5 main factors such as: Vulnerability (Factor 1), Density (Factor 2), Business Activities and Business with Hazardous Material (Factor 3), Seismic Hazard (Factor 4) and Potentials (Factor 5) respectively. The risky zones have been grouped into 5 categories and their factor loadings have been examined. The findings show that the loading of the seismic hazard component is getting higher through from risky zones to non-risky zones and contrary the loading of the vulnerability components is getting higher through from non-risky zones to risky zones. This differentiation is also an evidence of any kind of irregularity in urban pattern will considerably affect the earthquake risk in the city.

## ELEMENTS FOR AN EARTHQUAKE LOSS ESTIMATION MODEL FOR GREATER CAIRO – ID 273

*A. M. Moharram, Imperial College London, UK*

Monetary losses due to an earthquake hitting a developing country may have a very detrimental impact on the economy in addition to substantial mortality and injury levels. Following the adverse effects caused by the moderate Ms 5.4 event of October 1992, the need to model the risk inflicted by an earthquake occurring in or near Cairo was shown to be an essential tool in order to offset this threat in the future. In this context, estimating the ground-shaking hazard is carried out herein as a primary step in the earthquake loss estimation process and an inventory database for the existing building stock is built up as a second step. In the former, a scheme is followed to integrate data on geological structures, seismic sources, seismicity and surface soil conditions to build up an event-based hazard model for the area. A comprehensive study is carried out using a considerable number of boreholes, to produce a classification of different soil deposits based on the NEHRP scheme. Additionally, a relationship is established to extrapolate data from shallow boreholes to 30 m. In the second part of the investigation, a general overview of the history of seismic provisions in Egyptian codes is discussed. A number of maps obtained from local sources, which show the evolution and expansion of the building stock over the past century, are then utilised to provide the geographical resolution needed for earthquake loss modelling. These are supplemented by street surveys to obtain a more informed definition of the building models incorporating other missing - yet essential - variables, such as height. All the above sources, with the support of engineering judgement and expert opinion, are finally used to divide the city into a number of census tracts, or geo-codes, of uniform building and soil characteristics.

## EARLY WARNING SYSTEM FOR DEEP STRONG VRANCEA EARTHQUAKES – ID 504

*G. Marmureanu, National Institute for Earth Physics, Romania*
*C. Ionescu, National Institute for Earth Physics, Romania*
*A. Marmureanu, National Institute for Earth Physics, Romania*
*A. Grigore, National Institute for Earth Physics, Romania*

The deep earthquakes (MGR=7.9) generated in Vrancea area are particularly of interest for many countries in Europe since they cause destructive effects at large distances from Moscow to Roma. Innovative content: EWS is the first European system for real-time early detection and warning of the seismic waves in case of strong earthquakes. Its development, made in collaboration with Karlsruhe University is based on new concepts and models of risks caused by seismic phenomena. What does it do? EWS uses the time interval (about 28-32 seconds) between the moment when earthquake is detected by the borehole seismometers in the Vrancea epicentre and the time of the wave arrival to deliver timely integrated information in order to enable actions to be taken before a main destructive shaking takes place. What is its use? EWS automatically triggers: gas distribution nets (on 1977 earthquake, MGR=7.4, there were 380 people burnt), stopping critical opperations in airports, nuclear power plants, refineries, stopping trains and elevators in a safe position,alerting of hospital surgery rooms and starting of emergency generators (project on way) etc. For whom?. It can be included very easy in the user's infrastructure. An irradiator nuclear installation from "Institute of Atomic Physics",Bucharest is using the EWS. EWS is more than an IT tehnological system to detect,monitor and submit warnings and it should be viewed as part of an European real-time information system that provide rapid information, about an earthquake impeding hazard,to the public and disaster relief organizations before (early warning) and after a strong earthquake (shake maps). Shake Map, new product on work of National Institute for Earth Physics will provide a sound starting point for immediate loss estimation using such methods around of Europe for immediate post-earthquake decision-making. This EWS is one of the 20 „Nominees for 2006 European IST Grand Prize"

## PRELIMINARY SEISMIC RISK SCENARIOS FOR MALAGA, SPAIN – ID 659

*J. Irizarry, Institut Cartogràfic de Catalunya, Spain*
*A. Macau, Institut Cartogràfic de Catalunya, Spain*
*T. Goded, Universidad Complutense, Spain*
*D. Clavero, LYDICCE, Spain*
*A. Pazos, ROA, Spain*
*S. Figueras, Institut Cartogràfic de Catalunya, Spain*
*R. Garcia, LYDICCE, Spain*

Spain is characterized by moderate seismic hazard. Located on the south coast of Spain, the city of Malaga is affected by one of the higher seismic hazard levels expected within the country. According to the Spanish Seismic Code (NCSE-02), the seismic hazard for Malaga with a return period of 500 years implies a peak ground acceleration of 0.11g corresponding to an intensity of VII-VIII degrees. Because of its seismic hazard level, one of the goals of the ERSE (Realistic Scenarios of Seismic Risk in Spain) project is performing seismic risk scenarios for the Malaga city.

A preliminary study of seismic microzonation is being conducted; this study will include microtremor measurements in selected sites in the city, in order to obtain the fundamental frequency of soils. A geotechnical classification of soils was performed to evaluate transfer functions by applying numerical methods in order to characterize the soil response that will be considered in the vulnerability analysis. Soil effects in terms of intensity are evaluated using Arias Intensity computed from the ground motion obtained by a 1-D numerical method applied in different soil conditions.

Two vulnerability assessment approaches are being applied to the city of Malaga. The first one is based on the classification of the building stock of Malaga's districts according to the EMS-98 vulnerability classes and estimates damages using the damage probability matrices. The second approach classifies the vulnerability and estimate damages by implementing the vulnerability index method using the structural typologies distribution within the city. The preliminary seismic risk scenarios developed are based on the macroseismic intensity.

## REAL-TIME SEISMIC RISK ANALYSIS FOR EARLY WARNING APPLICATIONS – ID 850

*I. Iervolino, Università di Napoli Federico II, Italy*
*V. Convertito, Osservatorio Vesuviano, Italy*
*G. Massimiliano, Seconda Università di Napoli, Italy*
*G. Manfredi, Università di Napoli Federico II, Italy*
*A. Zollo, Università di Napoli Federico II, Italy*

Earthquake Early Warning Systems (EEWS), based on real-time prediction of ground motion or structural response

measures, may play a role in reducing vulnerability and/or exposition of buildings and lifelines. In fact, recently seismologists developed efficient methods for rapid estimation of event features by means of limited information of the P-waves. Then, when an event is occurring, probabilistic distributions of magnitude and source-to-site distance are available and the prediction of the ground motion at the site, conditioned to the seismic network measures, may be performed in analogy with the Probabilistic Seismic Hazard Analysis (PSHA). Consequently the structural performance may be obtained by the Probabilistic Seismic Demand Analysis (PSDA) and used for real-time risk management purposes. However, such prediction is performed in very uncertain conditions which have to be taken into proper account to limit false and missed alarms. In the present study, real-time risk analysis for early warning purposes is discussed. The magnitude estimation is performed via the Bayesian approach, while the earthquake localization is based on the Voronoi cells. To test the procedure it was applied, by simulation, to the EWWS under development in the Campanian region (southern Italy). The results lead to the conclusion that the PSHA, conditioned to the EEWS, improves significantly the risk assessment and that the false/missed alarm probabilities may be controlled by set up of an appropriate decisional rule and alarm threshold.

### CROSS-BORDER SEISMIC RISK SCENARIOS (EASTERN PYRENEES) – ID 902

*P. Roussillon, BRGM, France*
*J. Irizarry, ICC, Spain*
*M. González, CRECIT, Andorra*
*P. Delmotte, CSTB, France*
*O. Sedan, BRGM, France*
*T. Susagna, ICC, Spain*

Located on the border between Spain and France, the Pyrenees region is one of the most active seismic zones of the two countries. Its historical seismicity and recent tectonics data indicate a significant level of seismic hazard. Since 2003, the ISARD project (Information of Seismic Automatic Regional Damages) has been studying both the seismic hazard and vulnerability within the eastern part of Pyrenees in order to develop a common scheme for generating seismic risk scenarios that surpasses the countries' borders and provide preventive and operational information on the seismic risk to the local first-aid and crisis management organizations. This paper concentrates on the seismic risk scenarios developed for ISARD's pilot zones : Andorra and both Spanish and French Cerdanya regions.

Seismic risk scenarios are developed using three levels of vulnerability assessment based on different levels of input data and methodologies. The vulnerability assessment for Level 0 is based on the classification of the building stock of a municipality according to the EMS-98 vulnerability classes according to the age, height and location of the building stock. The Level 0 damage estimation is calculated for each municipality within the region using the damage probability matrix methodology. The second vulnerability assessment level, or Level 1, implements the vulnerability index method taking account soil effects applied to geographical subdivisions of the building stock according to their structural typologies distribution. The third and final vulnerability assessment level, namely Level 2, applies the capacity spectrum method to determine the expected damage level or damage probabilities associated to a structure. This Level 2 method is only implemented for some essential buildings in the region.

Seismic risk scenarios are expressed in terms of expected damages to the building stock and their consequences to the population such as the expected number of homeless, injured and casualties.

### EARTHQUAKE LOSS SCENARIO FOR THE EMERGENCY RESPONSE EXERCISE RHEINTAL 06 – ID 920

*O. Lateltin, Federal Office for the Environment, Switzerland*
*P. Smit, National Emergency Operations Centre, Switzerland*
*B. Duvernay, Federal Office for the Environment, Switzerland*

The earth will shake on the 17th of October 2006 at 5 AM local time in the Upper Rhine Valley, creating an emergency situation in Switzerland, Austria and the princedom of Liechtenstein. This magnitude 6.0 earthquake will be followed by an aftershock of magnitude 5.7 on the 18th of October at 7 AM.

This earthquake scenario has been prepared for a several days lasting exercise named "Rheintal 06". This exercise's objective is to test at all levels the collaboration between the different military and civilian command structures of Switzerland, Austria and the princedom of Liechtenstein. In parallel, several engagement exercises at specially prepared "damaged locations" will serve to test the collaboration between civilian and military emergency response units of these countries. Each involved unit will receive a script of the exercise with the tasks to be dealt with.

The consequences of the scenario earthquake in terms of building, human losses has been evaluated based on scarce building typology information, a qualitative consideration of the influence of the local geology, as well as with a simple model using a intensity based attenuation law and the European Macroseismic Scale EMS98 building description and vulnerability curves systematic. Even with this simplistic model and the inherent high level of uncertainty in earthquake damage evaluation, a realistic picture of the consequences of the scenario could be developed. In summary, out of a population of 425'000 in the considered area, the exercise considers 60 fatalities, 1'900 injured persons, 300 buried persons, 174'000 short term homeless persons and 30'000 long term homeless persons. Out of 130'000 buildings, the exercise considers 7'500 severely or totally damaged buildings (permanently inhabitable) and 36'000 buildings suffering average damage (inhabitable until inspected).

### HISTORIC CENTRES AND SEISMIC RISK – ID 970

*D. Benetti, Dipartimento della Protezione Civile PCM Italia, Italy*
*R. Ferlito, Dipartimento della Protezione Civile PCM Italia, Italy*
*P. Soddu, Dipartimento della Protezione Civile PCM Italia, Italy*

The development of criteria for the seismic vulnerability assessment of historical towns, is one of the activities promoted by the National Seismic Survey Office of Civil Protection Department (DPC-USSN) concerning protection of the Italian cultural heritage. The project is performed with the contribution of the Ministry for the Cultural Heritage, within the framework of a general agreement of cooperation, analogously to previous experiences on the same subject. The project is devoted to two main objectives: • the improvement of the cultural heritage database of national public administrations, collecting data regarding size, number, historic value and vulnerability of historical urban settlements exposed to seismic risk; • the assessment of the seismic risk for historical towns at national scale, through the estimate of the expected loss in terms of a Cultural Interest indicator. This parameter can be defined using the information collected, taking into account the historical and artistic characteristics of the town. This information will be collected in the "Atlas of Historic Centres Exposed to Seismic Risk". The "Atlas of Historic Centres Exposed to seismic risk" is a collection of information on the exposition and vulnerability of the historical centres exposed to seismic risk considered in both buildings complex and urban context. The Atlas collects cultural, urbanistic, environmental characteristics of every examined historic centre. The present work shows a methodology which aims to give a grade of Cultural Interest, and an estimation of expected loss in historic current buildings.

### INSURED LOSSES FOR REPEATS OF THE 1906 SAN FRANCISCO AND 1811/1812 NEW MADRID EARTHQUAKES – ID 1195

*L. Hall, Risk Management Solutions, United States*
*M. Rahnama, Risk Management Solutions, United States*
*D. Windeler, Risk Management Solutions, United States*
*G. Molas, Risk Management Solutions, United States*
*P. Seneviratna, Risk Management Solutions, United States*
*T. Onur, Risk Management Solutions, United States*
*A. Baca, Risk Management Solutions, United States*

At low probabilities the seismic hazard of the New Madrid region in the eastern US is observed to be similar to California, as in the east the lower event rates are counteracted by the slow attenuation of strong ground motion with distance. Construction type also differs between regions, where the building codes in the west have historically been significantly stricter, accentuating the hazard differences when calculating damage risk. Regional differences in penetration rate complicate the situation further when modeling losses from an insurance perspective.

This paper presents a comparison of the insured losses of the 1906 San Francisco and 1811/1812 New Madrid earthquakes if they were to occur again today. Results are calculated using RiskLink, a proprietary insurance loss-estimation tool. The source and ground motion models are based on the model parameters from the USGS 2002 hazard mapping project. Site classes were developed from geologic maps classified with published and inferred Vs30 data. Building damage has been estimated with a spectral-response based methodology. The insured exposure was estimated from population and economic factors.

New Madrid scenario insured losses are generally comparable to those of 1906 San Francisco event, although the numbers vary significantly between residential and commercial exposures. The key driving factors behind these results are investigated in detail, highlighting the different impacts of the regional variations in the ground motion, site response, vulnerability and insurance penetration rates.

## ANALYSIS OF TRIGGERING ALGORITHMS FOR DIRECT (ENGINEERING) EARLY WARNING SYSTEMS – ID 1198

*H. Alcik, KOERI, Bogazici University, Turkey*
*Y. Fahjan, KOERI, Bogazici University, Turkey*
*M. Erdik, KOERI, Bogazici University, Turkey*

The recent advances in seismic instrumentation and telecommunication technologies permit the implementation of early warning systems for major cities exposed to strong earthquake shaking around the world. An Early Warning System forewarns an urban area of the forthcoming strong shaking, normally with a few seconds to a few tens of seconds of early warning time before the arrival of the destructive S-wave part of the strong ground motion. An earthquake early warning system requires seismic stations close to the source of earthquakes and continuous communication between the seismic stations and a central processing station. For urban and industrial areas susceptible to earthquake damage, where the fault rupture system is complex and the fault-site distances are short, there is usually insufficient time to compute the hypocenter, focal parameters and the magnitude of an earthquake. Therefore, more simple and robust early warning algorithm is necessary, since this time is needed for the more complex alarm decision- making process. The direct (engineering) early warning systems are based on algorithms of the exceedance of specified threshold time domain amplitude levels. The continuous stations data of band-pass filtered peak ground accelerations (PGA) and the cumulative absolute velocity (CAV) are compared with specified threshold levels. Whenever selectable stations exceed these levels within selectable time interval, the first alarm can be declared

In this study, different algorithms based on PGA and/or CAV will be analyzed and verified for both fast triggering and reliability. The triggering threshold levels of PGA and CAV parameters will be studied and the effect of stations locations and configuration on triggering algorithm will be discussed.

## CURRENT STATE OF THE EARLY WARNING SYSTEM CREATION FOR YEREVAN CITY, ARMENIA – ID 1233

*A. Antonyan, Armenian NSSP, Armenia*
*V. Arzumanyan, Armenian NSSP, Armenia*

The capital of Armenia, Yerevan city, situated in the one of the most seismically active regions of the world, Armenian Upland. According to Armenian historiography this region has suffered by devastating earthquakes: Ararat (M=7.5) in 1319 and 1840y.y, Dvin (M=7.0) in 851-893y.y, Garni (M=7.0) in 1679y. and others. In present Yerevan city buildings and structures are designed on ground acceleration values of 0,1-0,2g, that correspond to 7-8 value by MSK-64 intensity scale according to seismic zonation map operating on the territory of Armenia up to 1994 and it is obvious that create high seismic risk. In 1998 the concept of EEWS for Yerevan city was developed in Armenian National Survey for Seismic Protection. The principle of action of EEWS was developed on the base of velocities difference between electromagnetic waves propagation ( 300.000 km/sec) and seismic waves ( 4km/sec). It was focused on the solution of the following tasks: possibility and efficiency of EEWS creation around Yerevan city, configuration of EEWS and determination of necessary number of seismic stations, gain in time of the warning in case of upcoming strong earthquake and others. In this paper we developed the new concept of EEWS for Yerevan city . An Earthquake Early Warning System for Yerevan city will have to face the fact that warning time for the most of relevant earthquakes will be extremely short. The system introduced here, therefore considered "Early Warning" in a wider sense, i.e., a system that involves Early Warning – as well as post earthquake rapid information component and expected damage estimation. The purpose of the paper is summarized the results on this problem.

## A VIRTUAL MONITORING PLATFORM ENVIRONMENT FOR RISK MANAGEMENT – ID 1277

*R. J. Scherer, Institute for Construction Informatics, Germany*
*G. Faschingbauer, Institute for Construction Informatics, Germany*

Handling crises requires making decisions, based on sufficient knowledge of the situation. New developments in ICT are to make the existing capacities of data and information usable in order to provide decision makers and task forces with the knowledge necessary for taking decisions as quickly as possible and hence to reduce response times considerably. Today, risk management systems are proprietary client server systems developed for particular hazards and specific scenarios, i.e. they are not open and scalable. Recent approaches have extended these client server systems to ASP technology. However, these application services, platforms and sensor systems are built on their own infrastructures, islands of functionality that cannot be easily shared and integrated in one logically common but distributed environment. In this paper we will present a novel ICT approach for a dynamically optimized management of emergency and crisis situations generated by natural hazards and industrial accidents. The main idea is a Scalable open Monitoring Platform Environment for Risk Management which will deliver a sustainable approach for ICT-based integration and information computing, based on engineering models and which will fundamentally improve the management and monitoring of natural hazards consequences by combining GMES and in-situ engineering sensing. The platform environment improves all phases of risk and crisis management, but in particular provides support for the response phase of hazards and crisis management. The architecture of the platform environment is modular and extendable, immediately available and highly distributed: this can be accomplished by the integrated combination of four main “state-of-the-art” and high potential technologies: (i) GRID technology, (ii) Semantic Knowledge Technologies (SKT), (iii) intelligent self-adapting sensor networks, and (iv) Virtual Organisation / Concurrent Engineering paradigms.

## STRATEGY FOR EARTHQUAKE DISASTER PREVENTION AGAINST THE APPROACHING MIYAGI-KEN OKI EARTHQUAKE, JAPAN – ID 1384

*M. Motosaka, Tohoku University, Japan*
*K. Tsukahara, OYO Corporation, Japan*
*S. Masuda, Tohoku University, Japan*
*M. Maeda, Tohoku University, Japan*

The Miyagi prefecture area in Japan is prone to be affected by a severe subduction earthquake so called “Miyagi-ken Oki earthquake”, which has an average return period of 37 years

and a very high probability of occurrence (about 50% within the next 10 years). The last earthquake (M 7.4) in 1978 caused severe damage in the area. A project for earthquake disaster prevention against the Miyagi-ken Oki earthquake, sponsored by governmental budget has been organized by collaboration of universities, municipal governments and industry. This paper describes the contents of the project and its approach oriented to develop a consistent work line interrelating basic, before-quake and after-quake countermeasures. Some of the main tasks are described in the next three paragraphs. The construction of an extended and interactive multi-layer Web-GIS system by compiling data provided by different organizations, in order to make possible the evaluation of the disaster prevention index from city units to the smaller ward units. Clarification of the earthquake risk differences within the region considering earthquake and geological circumstances. Comparative investigations of the earthquake risks of three local cities have been done together with incentive disaster prevention maps and computer graphics animations of expected damage patterns. A system for priority evaluation of retrofit of existing buildings taking into account site conditions and the Is-value (earthquake resistance index of the building) has also been developed. Effective use of real-time earthquake information considering the possibility of issuing earthquake warnings 15 seconds before S-wave arrival in Sendai. Early warning systems comprising evacuation, training and education functions have been developed and applied in the University Hospital, a distribution complex union and three elementary schools in the model area of three local cities. Furthermore, the data compiled form the earthquake observation network is efficiently used for the newly developed building damage identification system.

## INTENSITY-BASED RISK ASSESSMENT FOR EUROPEAN EARTHQUAKE REGIONS - THE 1995 AIGIO EARTHQUAKE – ID 1417

*T. Langhammer, Bauhaus-University Weimar, EDAC, Germany*
*J. Schwarz, Bauhaus-University Weimar, EDAC, Germany*
*P. Loukopoulos, Digeliotikon 73, Greece*
*L. Abrahamczyk, Bauhaus-University Weimar, EDAC, Germany*
*F. V. Karantoni, University of Patras, Civil Engineering Department, Greece*
*D. H. Lang, Bauhaus-University Weimar, EDAC, Germany*

The detailed survey of damage cases observed in the aftermath of the Ml 6.1 Aigio (Greece) earthquake of June 15, 1995 provides the opportunity to test GIS-based seismic risk assessment tools and to examine their applicability to earthquake regions of Southern Europe. For this purpose, the building stock, the main damage zones, and individual damage cases in the city center of Aigio are reconstructed. GIS-layers for the situation in 1995 and for the current building stock (in 2005) are developed. The vulnerability of the different building types is evaluated on the basis of the European Macroseismic Scale EMS-98 while damage grades are assigned to each building according to the observed shaking effects. In addition, instrumental site investigations were conducted at locations of severe damage and where subsoil profiles were available. The impact of ground conditions and topographic peculiarities is considered to test the improvement of the damage reinterpretation. Due to the different model assumptions and due to the stepwise refinement of input variables (GIS-layers) the scatter of prognoses can be quantified and compared to the reported and/or observed damage distribution. Studies are related to data layers of different quality and time: (1) The building stock is reconstructed based on a quick field survey immediately after the earthquake in 1995 and also based on interviews with inhabitants carried out ten years after the earthquake. Scenarios are related to a mezo-scaled level while predicting the mean damage grades within a grid of 50 x 50 $m^2$ area elements. (2) A building-by-building model is derived based on detailed damage documentation from the University of Patras. Later, predictions are provided for each building in terms of damage grades (i.e. on a micro-scaled level). In addition to the empirical intensity-based approach, typical RC frame buildings are analyzed in order to detect structural weaknesses and to determine their capacity curves.

## EXPERT SYSTEM FOR LOSS AND DAMAGE SCENARIO CALCULATIONS DEVELOPED FOR THE TBILISI METROPOLITAN AREA – ID 1440

*M. Elashvili, UNSSP, Georgia*
*Z. Javakhishvili, UNSSP, Georgia*
*T. Mumladze, UNSSP, Georgia*
*T. Godoladze, UNSSP, Georgia*

The Caucasus is one of the most seismically active regions in the Alpine-Himalayan collision belt. During the 20th century several destructive earthquakes with the magnitudes up to 7, intensity 9 (MSK scale) occurred in the Caucasus region, the strongest of them at the end of the century: During the 1988 Spytak earthquake in Armenia (M=7.0) 25 000 people were killed, 50 000 were injured and economic damage equaled nearly 15 billion Rubles. Just three years later in 1991 the Racha earthquake in Georgia occurred (M=7.0), More than 200 people were killed and, approximately 60 000 were left homeless. The damage covered thousands of square kilometers. The recent earthquake of April 25, 2002 in Tbilisi – capital of Georgia has once again reminded us of the importance of preparedness to natural catastrophes. More then 1.5 million civilians concentrated in Tbilisi, about the half of the total population of Georgia, it is doubtless that it is a main and dominant economical center. This issue is of concern not only to Georgia or the Caucasus, but to many other countries worldwide who have economical interests is Caucasus. Global projects such as the oil and gas pipelines crossing through the Georgia or Great Silk Road are depend upon seismic monitoring at worldwide standards. Seismicity study, delineation of active faults and potential seismic sources was done. An expert system based on GIS technology was created for emergency response needs. Geographical and geological spatial database were prepared for mapping and analysis of earthquake effect in case of strong event. Finally, based on the urban map of city and engineering specifications of typical buildings for Tbilisi, special tools for preliminary assessment of damage and losses were compiled.

## COORDINATING EARTHQUAKE INVESTIGATIONS – ID 1550

*C. Scawthorn, Kyoto University, Japan*
*T. Holzer, USGS, United States*
*C. Rojahn, ATC, United States*

The Plan to Coordinate NEHRP Post-Earthquake Investigations was published as USGS Circular 1242 (USGS, 2003). The Plan was subsequently exercised in three exercises based on scenario events: (1) a Hayward Fault Mw 7 event without foreshocks; (2) a New Madrid seismic zone Mw 7 event with foreshocks, and (3) a Puerto Rico Mw 8 subduction event on the Puerto Rican Trench accompanied by a tsunami affecting the eastern seaboard of the United States. Each exercise consisted of a four-hour telephone conference call with a web-based electronic link and post-exercise evaluations fed back to participants. Evaluation of the exercises found the Plan to be adequate, with implementation of the Plan by the NEHRP agencies improving with each exercise. A seminal component of the Plan is the technical information clearinghouse, a physical entity where much of the field coordination is accomplished. It was recognized following the three exercises that for some earthquakes the Plan and a technical clearinghouse may not be implemented despite field deployments by NEHRP parties, that a key recommendation was development of a Virtual Clearinghouse (VCH).

## AUTOMATIC FELT MAPS – ID 1711

*R. Bossu, EMSC, France*
*J. M. El-Baki, EMSC, France*
*M. Aupetit, CEA/DASE/LDG, France*
*S. Marin, CEA/DASE/LDG, France*
*G. Mazet-Roux, EMSC, France*

We propose a new tool which automatically maps within

20-25 minutes of the event occurrence, the geographical areas in which the earthquake has been felt.

Brutal increases of the number of instant visitors connecting on the EMSC web site are automatically detected. Such a synchronized action involving many individuals can only be explained if these individuals share a common reason to visit the EMSC web site at the very same time. We assume that they have just experienced the same earthquake.

After filtering out the IP addresses known to be from seismological institutes, a geographical location is assigned to each IP address comprised in this burst. The felt maps are then obtained by plotting the observed cluster. A statistical approach is being implemented to assess the significance of change in the visitors' origin in comparison to the average audience in the region.

This methodology has been tested since mid-2005 on about 20 earthquakes. The felt maps have been distributed to the seismologists of the country(ies) affected by the given event who validated the approach.

Obviously, it can only work when a significant number of individuals with Internet access have actually felt the event. In practice, this service works mainly for European earthquakes and the proximity of an urbanised region is the key parameter even when compared to the magnitude. A felt map was produced following a ML3.3 event as it occurred close to Zagreb (Croatia).

Despite these limitations, the felt maps is the quickest way offered to seismologists to automatically and easily collect information about the effects of an earthquake. It can work independently of any seismological data and theoretically (we hopefully had not such a case yet) it should be able to map areas where individuals are unable to access the Internet following the earthquake shaking.

## DATA ACQUISITION AND EARTHQUAKE ALERTING IN NORTHEASTERN ITALY: THE OGS-CRS EXPERIENCE USING THE ANTELOPE SOFTWARE SUITE – ID 1738

*D. Pesaresi, OGS, Italy*
*P. L. Bragato, OGS, Italy*
*P. Di Bartolomeo, OGS, Italy*
*G. Durì, OGS, Italy*
*A. Govoni, OGS, Italy*
*F. Ponton, OGS, Italy*
*D. Zuliani, OGS, Italy*

Since 2002, the Centro di Ricerche Sismologiche (CRS, http://www.crs.inogs.it) of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) is involved in the EU Interreg IIIA project "Trans-national seismological networks in the South-Eastern Alps" together to other four institutions monitoring the area (department DST of the University of Trieste and Civil Protection of Regione Autonoma Friuli-Venezia Giulia, Italy, ARSO, Slovenia, and ZAMG, Austria). The Antelope software suite has been chosen as the common basis for near real-time data exchange, rapid location of earthquakes and alerting. At CRS we have developed hardware and software solutions to integrate heterogeneous instrumentation in the common virtual network. Three sub-networks are merged: a broad-band network mainly based on Quanterra data loggers (Q4120 and Q330) with broad-band seismometers and accelerometers; a short-period Lennartz MARS88 network; an experimental network of inexpensive Internet Accelrographs IA-1 aimed to the rapid generation of detailed shake maps after major earthquakes. Data are transmitted by means of broad-band (6Mbps) spread-spectrum radio links using the IP protocol. In collaboration with the other partners, we are setting up the automatic procedures to locate earthquakes occurring both locally and worldwide, estimate their magnitude (ML, mB and Ms), dispatch alert messages by e-mail and short messages over mobile phones, update web pages describing the observed seismicity.

## EARTHQUAKE RISK RESEARCH IN ROMANIA - 10 YEARS OF COLLABORATIVE EFFORTS – ID 1749

*F. Wenzel, Geophysical Institute, Karlsruhe University, Germany*
*G. Schmitt, Geodetic Institute, Germany*
*E. Gottschämmer, Geophysical Institute, Germany*
*V. Sokolov, Geophysical Institute, Germany*
*B. Sperner, Geophysical Institute, Germany*
*D. Hannich, Department of Applied Geology, Germany*
*M. Böse, Geophysical Institute, Germany*
*M. Markus, Inst. for Techn. and Management in Construction, Germany*
*D. Lungu, Technical University of Civil Engineering, Romania*
*G. Marmureanu, National Institute for Earth Physics, Romania*

A Collaborative Research Centre 461 'Strong Earthquakes – From Geosciences to Civil Engineering' (http://www-sfb461.physik.uni-karlsruhe.de/) has been established in 1996 in response to the Kobe earthquake of January 17, 1995 that demonstrated the interdisciplinary needs of earth science and civil engineering. The Centre defined its regional focus in Romania, with Bucharest as the European city with the second highest risk after Istanbul. In addition to interdisciplinary work the cooperation with various Romanian institutions has high priority. The paper presents results of the tectonic studies in terms of a geodynamic model of intermediate depth Vrancea earthquakes, of site-specific probabilistic hazard assessment and the development of ground motion maps (Shakemaps) on urban and regional scale. Together with an improved Early Warning System key elements of an Earthquake Information System will be established. Another highlight is the development of a Disaster Management Tool (DMT) with modelling, decision support and communication components.

## GROUND MOTION ATTENUATION AND SHAKING MAPS GENERATION IN THE SOUTHERN ALPS AREA – ID 1811

*G. Costa, Dip. Scienze della Terra, University of Trieste, Italy*
*L. Moratto, Dip. Scienze della Terra, University of Trieste, Italy*
*D. Sandron, Dip. Scienze della Terra, University of Trieste, Italy*
*A. Delise, Dip. Scienze della Terra, University of Trieste, Italy*
*P. Suhadolc, Dip. Scienze della Terra, University of Trieste, Italy*

The attenuation laws for PGA, PGV and PSA (0.3 s; 1.0 s; 3.0 s) are computed for the Friuli area (NE Italy) using strong-motion recordings. 900 accelerometric waveforms of 123 earthquakes are selected from the RAF (1993-2005) and ISESD databases in a large magnitude range (3.0 <= Ml <= 6.3). The epicentral distances vary from 1 km to 100 or 200 km. The signals are filtered and the frequencies varied from 0.1 Hz to 30 Hz. Different attenuation models are tested and attenuation relation parameters extracted for both vertical and horizontal components (largest component and vectorial addition). The best model includes effects due to local site conditions, near-source and magnitude saturation. Fixing the epicentral distance, for low magnitude values our model estimates lower peak ground accelerations than those proposed in previous studies. The derived attenuation laws are inserted in the TriNet software to produce, together with real-time data, ground-shake maps for NE Italy. The software is calibrated with recordings of important past seismic events in the studied area in order to produce realistic and consistent real-time shakemaps for future earthquakes.

## RAPID MOMENT TENSOR SOLUTIONS IN SWITZERLAND – ID 1917

*J. Clinton, ETH, Switzerland*

Rapid and accurate knowledge of an earthquake's magnitude and fault characteristics are vital in estimating the damage caused by a major event, for emergency response, and determining the potential for tsunami generation. The Swiss Seismological Service (SED) at ETHZ has been producing moment tensor solutions following moderately large regional and small local earthquakes since 1999. A suite of broadband inversion methods - developed both internally and by other research groups - have been used. Regional moment tensors for events in the European-Mediterranean area with M>4.7 are determined using time series inversion of 50 - 100s broadband data within 20o of the epicentre, and are automatically available 90 minutes after event nucleation (Bernardi et al., 2004). Local moment tensor solutions are calculated manually

for Alpine events with M>3.0 (Braunmiller et al., 2002). Both solution sets are available on-line. Data used in the inversions is gathered from a number of European and global networks. In many regional networks in the US and Japan, automated moment tensor solutions are available within 10 - 20 minutes of an event. This presentation summarises the current moment tensor operations at SED, and discusses improvements in data acquisition and numerical methods. These are aimed at reducing the time taken to produce a solution, whilst maintaining or improving the solution quality.

### EARLY WARNING LOCATION OF SINGLE AND MIXED EVENTS USING NETWORK BEAMFORMING – ID 1979

*V. Pinsky, Geophysical Institute of Israel, Israel*
*S. Horiuchi, NIED, Japan*

The problem of reliable and accurate seismic event location is a key issue in seismic events monitoring for early warning systems. This issue is determined by how we manage to fight various detrimental factors such as sporadic seismic noise, poor network configuration, heterogeneity of Earth, wrong phase association or multiple event manifestation.

For this purpose we started development of a robust sparse network location technique, based on array location principles: Network Beamforming (NB), which processes bulletin phase arrival time data via the use of complex exponents in a grid-search for the maximum semblance in hypocenter space. The use of the robust semblance statistic provides reliable and fast phase association and location results for 1D and 3D Earth in local, regional and teleseismic distance ranges, effectively separates double events and associates depth phases. The method is working in combination with several automatic picking approaches and effectively resists to false readings.

### TSUNAMI INUNDATION MAPS THROUGH THE GIS GRASS – ID 2037

*F. Bacino, University of Genova, Italy*
*P. Poggi, University of Genova, Italy*
*T. Cosso, DIMSET-University of Genova, Italy*
*B. Federici, DIMSET-University of Genova, Italy*
*L. Landò Rebaudengo, DIAM-University of Genova, Italy*
*D. Sguerso, DIMSET-University of Genova, Italy*

Important instruments for the decision-making process that public administrations may use are maps of the realistic effects that distructive natural events may produce. In the present work we have predisposed a GIS procedure to realize Tsunami Inundation Maps with the software open source GRASS. Such procedure was then applied to a reach of the Ligurian coast, a particularly densely populated areas, in the north-west side of Italy. Input data is the tsunami ashore wave height (see Bacini et al., session CS8). Then, the model uses the Digital Terrain Model and the Land Use Cartography (or aerial photographs to classify if Land Use Cartography is not available) to take into account terrain morphology (slope, aspect, etc.) and its roughness due to vegetation and settlements, in the evaluation of wave run-up and its propagation inside the coast. A detailed description of the procedure will be reported at the conference. The whole procedure was applied to a test area characterized by either gentle slope beaches without protection and rock cliffs, obtaining realistic results. Note that, due to the fact that in the Mediterranean sea the time between the generation of an earthquake or a landslide and the coming of the tsunami wave on the coast is very limited, these maps might have an informative and preventive function: to improve the sensibility of the population on this particular hazard, and to indicate to public administrations that crucial structure (like harbour, depuration systems, hospital, school, road, railways, etc.) should be protected to manage better the emergence. Obviously, to reduce the negative impact of tsunami events, it's really important to produce these maps as soon as possible; furthermore, if you suppose the fast determination of source parameters, our model allows real-time alert map as an important starting point for a real-time damage prediction.

## CS7: Strategies in Earthquake Mitigation
Level 2

### EARTHQUAKE LOSS MODELLING FOR SWITZERLAND FOR INSURANCE AND REINSURANCE PURPOSES – ID 40

*M. Simic, Benfield, UK*

This paper discusses the design and results of a proprietary model for calculation of earthquake losses in Switzerland. Benfield has been one of the pioneers of loss modelling for insurance and reinsurance purposes in late 1980s and early 1990s. The models, known as GAPs (Geographic Analysis Projects), are now created and maintained by Benfield ReMetrics Natural Hazards Team. GAPQuake Switzerland, a probabilistic model for calculation earthquake losses in Switzerland, was conceived and released in 2002. As background, the paper describes earthquake insurance and reinsurance in Switzerland with particular emphasis on pooling arrangements that exist in the country with highest insurance penetration in the world. The core of the paper concerns the constituent components of any loss model - hazard, vulnerability, exposure and statistical/financial aspects of loss calculation. The discussion of the hazard component revolves around fact that Switzerland is a country of moderate seismicity which carries significant uncertainties when trying to extend the historic catalogue to synthetic catalogue lengths required for reasonably accurate predictions of loss return periods of the order of several hundred years, where reinsurance is at its most effective. The vulnerability component was designed around the EMS-98 scale, which permitted estimates of not just relative damage ratios but also of the number of damaged properties, which is of crucial importance when assessing the impact of primary insurance deductibles. The exposure component discusses the issue of aggregation of insurance data (e.g. canton vs. postcode) and importance of granularity of calculation cells on loss results. The loss calculation module is mainly concerned with statistical and financial aspects. The results of earthquake loss modelling are discussed on three examples of direct relevance to the understanding of earthquake risk in Switzerland and consequential purchase of reinsurance cover in worldwide markets.

### STRATEGY IN EARTHQUAKE RISK REDUCTION FOR EXISTING BUILDINGS – ID 71

*A. K. Sinha, C.M.E, India*

The fools will say, "We shall see when the problem will come". Clever ones, when aware of the risk they are exposed to, will never wait for the problem to come before and then find ways to encounter it. They shall make themselves prepared to face the problem whenever it comes. Yes, preparedness is the demarcating aspect between the two. This is more relevant in the case of natural disasters like earthquakes, which are highly uncertain in their occurrences. Making all possible contingency arrangements under available resources beforehand can be termed as "Preparedness". Awareness of the seismic risk is the first step in making wise people act in making themselves safer. One will try to find ways within his means to reduce the risk one is faced with.

Their role stakeholders in seismic risk mitigation has been emphasised in this paper. Insurance, legislations, penalties and awards/concessions, etc have been traced a non-technical aspects in the overall seismic disaster mitigation strategy. Urban and regional planning is also a part in the seismic risk reduction. Preparedness in terms of rescue as immediate post disaster emergency action has been seen as another important requirement. Comparison of pre and past disaster scenario with regard to seismic disaster reduction strategy has also been traced out in this paper.

Seismic vulnerability investigations at micro as well as macro level are required for effective implementation of retrofitting and

rehabilitation actions. A three level approach, RSD, involving Rapid Assessment Method (RAM), Simplified Assessment Method (SAM) and Detailed Assessment Method (DAM) has been evolved for indicating seismic vulnerability at each level. The aim is to use appropriate level for analysing structures with different complexities and depending on the purpose of such analysis. This part covers the technical aspects of the seismic disaster mitigation strategy.

### DEVELOPMENT OF PASSIVE EARTHQUAKE PROTECTION TECHNOLOGIES IN TURKEY – ID 162

*M. Kaya, FIP Industriale S.p.A, Turkey*
*S. Tezcan, Bogazici University, Turkey*
*M. G. Castellano, FIP Industriale S.p.A, Italy*

Passive earthquake protection systems which can be classified as seismic base isolation and energy dissipation devices are considered to be mature technologies mitigating earthquake hazard for civil structures and their contents reducing the seismic vulnerability of architectural heritage. Turkey, a country with an architectural and cultural heritage of thousands of years experiencing damaging earthquakes of M=6,5 and above at intervals of two years, hit by the most catastrophic and disastrous earthquake of it's history with respect to it's social and economic consequencies in August 1999. With a conscious for protecting the nation from potential damaging earthquakes and conveying the histroric heritage to next generations, the country is paying more attention to innovative anti-seismic systems, so called passive earthquake protection technologies. Conventional intervention techniques do not often endow structures with sufficient resistance against a maximum expected earthquake and cause changes in the original structural configuration not acceptable from the standpoint of conservation of historic values . This paper aims to present the various aspects of the development of innovative passive earthquake protection systems in Turkey starting from the Turkish Earthquake Code and concluding with the recent applications and intentions.

### STRATEGY OF BUILDINGS OPERATION IN EARTHQUAKE PRONE AREAS – ID 191

*V. Vorobiev, Saint-Petersburg Transport University, Russian Federation*
*O. Sakharov, Saint-Petersburg Transport University, Russian Federation*
*A. Uzdin, Saint-Petersburg Transport University, Russian Federation*

The problem of the buildings operation planning in seismic area is considered in the report. This planning includes the processes of building designing, construction and operation. It uses performance based designing principles, taking into account that design scenarios of damages accumulation can vary during the time of structure life. As the characteristic of the degree of antiseismic structures strengthening authors use the concept of the structure seismic stability class (SSC) Ks, equal earthquake magnitude for which the construction is designed. Considering the group of limiting conditions the corresponding group of SSC is to be used. Using two limiting conditions that is the limit state (LS) and the ultimate limit state (ULS) it should to considere two classes of seismic stability that is minimal and maximal . For objects of mass construction the parity takes place. It allows to regard as a first approximation of the measure of structures seismic stability the minimal class of seismic stability The operation scenario of structures provides • setting the initial design input level of seismic loads (DIL), • planning of the repair time points with DIL setting for repair designing • development of approaches to buildings insurance upon seismic impacts • the decision of re-profiling buildings questions For the decision of the above mentioned questions are taken into account ∼ capital expenses for antiseismic strengthening (K), ∼ profit of buildings operation (P), ∼ time of buildings malfunction after earthquakes (t), ∼ buildings service life (T), ∼ repeatability of an earthquake with magnitude I on MSK scale for the building site L(I), ∼ damages caused by the earthquake for the building having the minimal SSC . Questions of risk management due to a choice of terms and volumes of structures reconstruction, and also due to an establishment of insurance payments and entitlement payment are analysed.

### EARTHQUAKE PROBABLE MAXIMUM LOSS VS. A MULTIHAZARDS APPROACH FOR A COMPULSORY INSURANCE IN ROMANIA – ID 349

*E. S. Georgescu, NATIONAL INSTITUTE FOR BUILDING RESEARCH - INCERC, Romania*

The paper present the potential and circumstances of earthquake catastrophe in insurance terms, considering also other hazards. The seismic setting of Romania is peculiar in what concerns the large exposure to each Vrancea great subcrustal earthquake (over 50 % of territory, whole S-E of country, as in 1940 and 1977). Over 33 % of land is exposed also to high flood risk, as in 1970, 1975 and especially in 2005. The pre-1940 high-rise structures are at higher seismic risk, while a large number of rural houses are mostly at flood risk. There is a Government Ordinance on Seismic Risk Reduction of Existing Buildings since 1994, with a system of subsidies, but the speed of owners reaction to contract rehabilitation works is rather low. Romania is the most important purchaser of catastrophe reinsurance in Central and Eastern Europe and a scheme of compulsory insurance for natural disasters, backed by Romanian Government, is under debate since 2002. Earthquake losses reached some 2 Bln, US Dollars in 1977, while the floods reached some 700 Millions Euro losses in 2005. Thus, one should take into account the flood risks, possibly as succeeding events in conjunction with earthquakes. The main difficulties addressed in the paper are related to: - need of modelling softwares and tarrif catalogs, apropriate for Romanian conditions; - a correct assessment and modelling of Probable Maximum Loss, from earthquakes, floods and other hazards, in reasonable combinations, reflected in affordable premiums, using tarrifs based on specific vulnerability of Romanian buildings; - a legal and technical framework of loss evaluation and adjustment, payment of compensation, etc., to be useful for a real vulnerability reduction after damaging events; - a system of recording of damaged buildings for vulnerability reduction and insurance protection, both in case of paid compensations as in that of values below deductibles.

### RESTORATION EXPERIENCES OF HISTORIC BUILDINGS DAMAGED IN THE1999 CHI-CHI TAIWAN EARTHQUAKE – ID 366

*C. Ja-Shian, National Cheng-Kung University, Taiwan*
*S. Jen-Chien, Council for Cultural Affairs, Taiwan*

On September 21,1999, a strong earthquake with Richter scale M=7.3 struck the middle area of Taiwan. In this earthquake and the following aftershocks, besides the collapse or damage of numerous school buildings, apartments, and commercial buildings, several hundred historic buildings were also destroyed or suffered serious damage. After earthquake, the major part of the restoration of damaged historic buildings are proceeded by the government. Until this year, the more than six-year post-earthquake restoration project will be completed, and most of the earthquake damaged historic buildings will be in a new stage. In this study, the experiences generated from the near hundred restoration cases in the passed six years will be summarized and presented. The experiences can be categorized as following: 1. The operation of related government divisions. 2. Mechanism of restoration quality control and supervision. 3. Traditional handcraft and the adoption of modern technology. 4. The introduce of rehabilitation. Recently, the conservation of cultural heritage is highly concerned by the government and the society of Taiwan. The historic building restoration experiences obtained after the 1999 Chi-Chi earthquake are valuable for future cultural heritage conservation. Also they are the bases for further study that historic building conservation related.

### PRIORITY OF SEISMIC RETROFIT OF BRIDGES CONSIDERING PREVENTION OF ISOLATED AREAS AFTER AN EARTHQUAKE – ID 407

*Y. Nariyuki, The University of Tokushima, Japan*
*J. Ohki, The University of Tokushima, Japan*
*T. Minamoto, The University of Tokushima, Japan*
*K. Hirao, The University of Tokushima, Japan*

In order to reduce losses and disruption to daily activities of regions due to damage to lifeline systems, a disaster management program needs to be developed and implemented. This kind of program generally consists of pre-disaster activities, emergency response activities and post-disaster recovery activities. The pre-disaster activities include risk assessment, risk mitigation and planning. Among these, risk mitigation represents any preventive actions taken before the occurrence of a disaster to reduce its consequences. Retrofitting of existing road bridges to increase their strength is one of the most important actions. However, in general, it is very time consuming and costly. Because the extent of retrofitting is limited due to economic constraints and also earthquakes are an unpredictable phenomenon, a bridge prioritization methodology for retrofitting decisions is necessary. It is obvious that post-seismic disaster activities are impossible in isolated areas due to damage to bridges and therefore prevention of isolation of disaster areas is very important for safety of the population during emergency period. The objective of this study is to develop a bridge prioritization methodology for seismic retrofitting with top priority to prevention of isolation of disaster areas during emergency period. This period is divided into three sequential time segments; refuge, rescue and emergency repair activities respectively. Though the road network is constant during all time segments, network characteristics depend on the segment because origins and destinations are not fixed during these segments. An index for assessing the effect of retrofit of road bridges on recovery of road network regardless of the existence of isolated area was proposed. This method was applied to a simplified model of road network in the central part of Tokushima City, Japan. Results of this study showed that retrofitting road bridges according to priority was useful to decrease the number of casualties in the emergency period.

### SOCIO-ECONOMICAL SUSCEPTIBILITY OF DISASTER MANAGEMENT PROGRAMMING – ID 431

*B. Esmailzadeh Hakimi, Vandidad Sazeh, Iran (Islamic Republic Of)*
*V. Farimehr, Vandidad Sazeh, Iran (Islamic Republic Of)*

Disaster management must be regarded as an integral technology concerning safety management of society to follow targets of socio – economical development programming of countries. Not a single solution can be accepted for all communities as disaster management measures. Therefore sophisticated and experimental studies on local opportunities and hazards must be taken into account and documented in order to localize global criteria and methods. Governmental, private and NGO organizations should participate in such a program to guarantee the program's effectiveness and influences. In this paper the influences of Iran's socio-economical vulnerability of society on disaster management methods and disciplines has been discussed and an integral perspective of disaster management to consider global socio –economical concerns has been proposed.

### EARTHQUAKE, THE PIVOT OF SUSTAINABLE DEVELOPMENT IN EARTHQUAKE PRONE COUNTRIES – ID 487

*H. Khashee, MPO, Iran (Islamic Republic Of)*
*B. Pourseyyed, MPO, Iran (Islamic Republic Of)*

Iran with a variety of natural disasters in large scale is located in an earthquake prone zone. Iran is the worst-hit country in the world in terms of earthquakes, (the UN 2004). Except some small areas in south-west and center of Iran, other parts are located on moderate and high level of seismic risk. Although seismic rehabilitation and strengthening plan of important public and state buildings, infrastructures and lifelines had been codified prior to Bam earthquake on 25 December 2003, the notification of 4th development plan of the country has been affected by this earthquake so that earthquake has been considered as one of pillar development issues, and seismic rehabilitation and strengthening plan has been comprehensively developed into seismic risk reduction plan. In earthquake prone countries, sustainable development could not be achieved unless this natural phenomena are considered in macrostructures and state planning of development. This paper while introducing different applied patterns in risk reduction plan, states the importance and the role of earthquake as one of the pivots in sustainable development and also seismic rehabilitation of building and infrastructure outputs in Iran.

### MULTIFACTORIAL RISK ANALYSIS AND SUSTAINABLE URBAN SAFETY – ID 517

*M. Klyachko, Centre on EQE&NDR (CENDR), Russian Federation*
*L. Puterman, Russia R&D Institute of Urbanistics, Russian Federation*

Development and application of aggregate risk analysis (AGRA) are under consideration. Multipurpose and target disaster scenarios (DISC) and maps of risk, as a complex apparatus for risk awareness & management, are step by step carried out and improved by means of methodical tools developed and implemented before. Standard procedure to elaborate the maps of seismic risk consists of few stages: - database collection and ordering for the GIS's use; - modeling territorial surface and population distribution; - filling the block-matrix of damage-forming factors; - inventory of built environment; selecting Basic Objects for Analysis of Buildings (BAOBABs), including dangerous and other critical facilities; - structural vulnerability analysis; - damage & loss estimation; - risk assessment and mapping. This stages & such new important documents as Passports of Safety are worked out in territorial (1:200000), municipal (1:10000) & object scales. Simultaneously multipurpose DISC MARIA (Multi-Aggregate RIsk Analysis) united with RIMMA (RIsk Mitigation & MAnagement) are carried out and apply for sustainable safety. Effectiveness of various preventive measures (the risk monitoring & control) can be provided by means of the duty scenario DISCONT. Typical approaches, assumptions and professional misunderstanding, which cause something to be in error, are studied and discussed, here are: - seismomicrozonation & real soil-structural interaction; - correct assigning the seismic impact by means of intensity; - structural vulnerability classification and estimation; - transportation, lifelines & city planning vulnerabilities and human respond/behavior. Authors pay attention for reverse influence of degradating environment on the increase of impacts on the structures surround. Criteria of permissible and acceptable risk and other fields of application of risk analysis are also under consideration, accompanying with examples implemented into practice.

### SEISMIC RISK MANAGEMENT FOR BUILDINGS PORTFOLIO OWNER - INTEGRATION IN AN ERP SOFTWARE – ID 563

*V. Pellissier, EPFL, Switzerland*
*B. Duvernay, FOEN, Switzerland*

One of the major challenges to guarantee the continuity of businesses is to take the risks that they are facing into account in order to manage them at best. The seismic risk that threatens the existing building stock and the related business activity is one of the concerns of the risk managers. The Swiss Institute of Technology of Lausanne (EPFL) [www.epfl.ch] develops its research and teaching activities in buildings with a cumulated value of about on billion swiss francs. In order to follow the integral risk management strategy put in place by the general management, it has been decided to evaluate the seismic risk of the building portfolio based on a method taking into account the specificities of the EPFL buildings (pile foundations, contiguous buildings of

great dimensions, concentration on a single site). To proceed, a 4 steps procedure has been chosen: Step 1: site specific spectral microzonation and pile foundation behavior, step 2: building prioritization using risk indicators [companion paper, Mittaz et al., 2006], step 3 in depth evaluation of buildings with the greatest risk potential, step 4: structural interventions. This paper presents the integration of the two first steps of this methodology in the Enterprise Resource Planning Software used by the EPFL. It details the benefits of this integration for a time evolutive management. It also presents the geographical representation and reporting tools developed for the risk managers.

### SEISMIC RISK ASSESSMENT OF INFORMALLY BUILT CONFINED MASONRY HOUSES IN PERU – ID 626

*M. Blondet, Catholic University of Peru, Peru*
*N. Tarque, Catholic University of Peru, Peru*
*J. Velasquez, Catholic University of Peru, Peru*

Confined masonry is considered "noble material" by Peruvian inhabitants and is therefore preferred for residential housing construction in Peru. Many Peruvian inhabitants do not have the possibility of hiring professionals and build their masonry houses with untrained help. Most of these houses have serious architectural and structural problems and are seismically vulnerable.

This paper summarizes the results of a research project in which a methodology was developed to rapidly estimate the seismic risk of informal confined masonry houses. This methodology was applied to a sample of 270 houses located in 5 Peruvian cities. The collected data involved location and architectural, structural and constructive characteristics of the houses. The information obtained was processed to determine the seismic risk of the houses against severe earthquakes (0,4g), and a database was elaborated to classify the main defects found.

The results obtained led to the development of a masonry booklet for the construction and maintenance of confined masonry houses in zones of high seismic hazard. The booklet presents every step of the construction process with illustrations and simple language and has been translated into English thanks to the support of the Earthquake Engineering Research Institute (EERI). Both Spanish and English versions are available from the website of the World Housing Encyclopedia of the EERI (http://www.world-housing.net/Tutorials/Tutorial.asp). It is hoped that the booklet will help informal masons in seismic areas to build structurally sound and safe houses.

### ACTUAL SITUATIONS OF INFORMATION SHARING CONCERNING VULNERABLE PEOPLE – ID 781

*M. Sotoma, NIED, Japan*
*M. Amami, NIED, Japan*
*Y. Hada, NIED, Japan*
*T. Suzuki, NIED, Japan*

It is well known that the information sharing is effective to mitigate damages due to disasters. Such a lesson learnt from the past events of disaster, however, was not necessarily reflected in actual operation of disaster countermeasures. In order to get rid of a lack in information, a research project on disaster mitigation using crisis-adaptive information sharing technology was commenced in July, 2004. It is a joint research of 12 different organizations funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan. National Research Institute for Earth Science and Disaster Prevention (NIED) is in charge of leading the project, representing 12 organizations. The research reported here is carried out as a part of the project. An examination is given on the information necessary for effective response to disasters. Investigations are carried out based on questionnaires and interviews to personnel of local governments who responded to an actual disaster. The information concerning vulnerable people, aged persons and disabled persons for example, are one of the most important information even in those necessary for disaster mitigation. This paper reports actual situations in headquarters of disaster countermeasures in local governments of Japan on the information sharing concerning vulnerable people at the time within a few days after a disaster occurred. In this paper, information regarding vulnerable people used in headquarters of disaster countermeasures in local governments is demonstrated first. Next, common routes for the transmission of such information are extracted. Then, problems with should be solved in information sharing for vulnerable people and their transmission routes are discussed. Finally, important items, which should be considered to reduce a victim of vulnerable people in a disaster, are summarized.

### AN INVESTIGATION ON SHARING OF DISASTER INFORMATION IN LOCAL GOVERNMENTS IN JAPAN – ID 830

*M. Amami, NIED, Japan*
*M. Sotoma, NIED, Japan*
*Y. Hada, NIED, Japan*
*T. Suzuki, NIED, Japan*

It is well known that the information sharing is effective to mitigate damages due to disasters. Such a lesson learnt from the past events of disaster, however, was not necessarily reflected in actual operation of disaster countermeasures. In order to get rid of a lack in information, a research project on disaster mitigation using crisis-adaptive information sharing technology was commenced in July, 2004. It is a joint research of 12 different organizations funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan. National Research Institute for Earth Science and Disaster Prevention (NIED) is in charge of leading the project, representing 12 organizations. The research reported here is carried out as a part of the project. An examination is given on the information necessary for effective response to disasters. Investigations are carried out based on questionnaires and interviews to personnel of local governments who responded to a natural disaster. This paper reports what kind of disaster information they share at the time within a few days after a disaster occurred. First, the sharing situation of information related to life on human damage and building damage is described. Next, the sharing situation of road traffic information is described. Then, the problem about sharing of disaster information that we got from this investigation is described. Finally, important items which should be considered about sharing of disaster information for disaster mitigation are mentioned.

### SEISMIC RISK MITIGATION IN MEGACITIES : DELHI EXPERIENCE – ID 835

*S. Akhilesh, Kyoto University, Japan*

Delhi, the capital of India, is extremely vulnerable to seismic hazards and can experience earthquakes of 5.5 to 6.7 on ricter scale (MSK intensity VIII). Its densely populated areas with large amounts of unsafe building stock, non-engineered structures, the sizeable number of unauthorised colonies and urban slums compound vulnerabilities in this thickly populated megacity. The safety of Delhi is prime as the national capital, the hub of national government business, multiplying many-fold the implications of a major earthquake, not only on the population of Delhi and its infrastructure but also on the functioning of the country itself. Keeping this in mind, Government of India and UNDP initiated Disaster Risk Management Programme, which aims to the socio-economic development goals of the stakeholders by enabling them to minimize losses to development gains and to reduce their vulnerabilities to disasters. The programme takes community based approach to disaster management hence seeks to build capacities of communities, government functionaries and other stake holders at all levels. Due to highly complex community structure in an urban area, the biggest challenge was how to engage urban communities in seismic risk mitigation activities. However, with innovative, sensitive to community needs, target based, user oriented community based disaster preparedness activities, the overall climate for seismic preparedness and mitigation is changing positively. The main initiatives were as follows:- awareness Generation: among government functionaries, technical institutions, NGOs, CBOs and communities about earthquake vulnerability and possible

preventive actions. Development of a Techno-Legal Framework: To promote safe construction and systems to ensure compliance. Disaster Management Plans: Development and Institutionalizing of Earthquake Preparedness and Response Plans and practice these through mock drills.

Capacity Building: For certification by Government functionaries and engineers and architects.

The successful initiatives has marked remarkable change in community perceptions and preferences towards a seismically safe built environment in Delhi.

### INFORMATION SHARING CONCERNING LIFELINE UTILITIES IN DISASTERS IN JAPAN – ID 854

*Y. Hada, NIED, Japan*
*I. Suetomi, NIED, Japan*
*T. Suzuki, NIED, Japan*

It is well known that the information sharing is effective to mitigate damages due to disasters. Such a lesson learnt from the past events of disaster, however, was not necessarily reflected in actual operation of disaster countermeasures. In order to get rid of a lack in information, a research project on disaster mitigation using crisis-adaptive information sharing technology was commenced in July, 2004. It is a joint research of 12 different organizations funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan. National Research Institute for Earth Science and Disaster Prevention (NIED) is in charge of leading the project, representing 12 organizations. The research reported here is carried out as a part of the project. Authors have been tackling information sharing of lifeline utilities (such as power, city gas, telecommunication and road traffic) in disasters for reducing damages. In this paper, the present situation of information sharing concerning lifeline utilities in Japan is reported. Our developed prototype system for sharing lifeline information is introduced. First, it is arranged that several information that lifeline utilities require and also can provide in disasters. Using those results, possibility for sharing information on disaster mitigation and its effects are discussed. Second, Connecting between information systems of lifeline utilities and other systems is examined using the developed prototype system for city gas. Further more, issues on connecting an information platform that this project has been developing to existing information systems and requirements for the platform are discussed.

### BUSINESS IMPACT AND RESTORATION MODEL FROM TSUNAMI DISASTER – ID 883

*Y. Kuwata, Kobe University, Japan*
*S. Takada, Kobe University, Japan*
*C. Dinesh, Kobe University, Japan*

Recently the interest to Business Continuity Management (BCM) is increasing among government, other local governments and business organizations, meanwhile destructive natural disasters such as earthquake, tsunami, flood and typhoon occur all over the world. The BCM can be defined as that critical business function which involves the preparation of plans, the allocation of resources and the implementation of processes such that an organization can recover quickly and safely from an interruption (crisis, emergency, event, etc.), with minimum negative impact to people, premises, assets and operations. The idea of BCM does not bring own company profit, but also plays a role of corporative social responsibility, especially in case of natural disaster. Therefore, the assessment methodology to evaluate quality and quantity of the facilities damaged under hazardous events and to estimate the interruption days of business activity is explored at the first stage of developing components of the BCM. This study proposes a method to evaluate business operation function after the earthquake and tsunami disaster. This method has several modules such as damage estimate by natural hazard, restoration rate-to-day model for building, equipments and lifeline facilities, and the business operation function introduced by facility restoration rate and its importance factor. As a case study, the tsunami impact to industries surrounding the sea coast and its subsequent restoration process were studied based on an interview survey in the south of Sri Lanka, after the 2004 Indian Ocean Earthquake and Tsunami. Several parameters in the business function module are estimated from the obtained database. The proposed method can simulate restoration process well and would contribute to the business continuity planning in future.

### NUMERICAL INVESTIGATION OF SUBSOIL INTERVENTIONS TOWARDS STRUCTURAL SEISMIC RISK MITIGATION – ID 953

*E. Kirtas, Aristotle University of Thessaloniki, Greece*
*E. Rovithis, Aristotle University of Thessaloniki, Greece*
*K. Pitilakis, Aristotle University of Thessaloniki, Greece*

Structural strengthening and soil stiffness upgrading are currently the dominant means of seismic risk mitigation in potentially vulnerable under strong ground motion structural cases. Several alternative techniques to reduce structural vibrations using subsoil interventions have been studied in the case of train-induced motions, yet little research has so far taken place in the field of earthquake-type excitations. The scope of this paper is to investigate the efficiency of both common and more innovative earthquake risk-reduction techniques, related to modification of foundation soil conditions, in terms of the dynamic interaction taking place between soil, structure and applied intervention. Several modification schemes including also techniques with a possible strong effect on the seismic wave propagation pattern, such as the isolation of the soil-structure system, are examined. Along these lines, existing and innovative materials with specified properties are implemented in the construction of such mitigation solutions. The mitigation effect of each intervention method on the ground and structural response is investigated using FE numerical analysis, after validation through centrifuge testing of soil-structure interaction systems. Seismic excitation is applied at the bedrock level, resulting in modified soil-structure interaction phenomena with each different intervention scheme, implicating single and multiple degree-of-freedom structural models. Both simplified harmonic motions and actual seismic recordings are examined and the role of several parameters affecting the phenomenon, including the structural and soil deposit dynamic characteristics, is highlighted. Analysis results reveal the existence of specific frequency ranges where significant reduction of structural response can be achieved under certain conditions. A discussion concerning the sensitivity of the resulting mitigation emphasizes on the advantages and disadvantages of each case examined.

### RVS METHOD FOR HEALTH FACILITY SEISMIC VULNERABILITY EVALUATION – ID 976

*G. Trendafiloski, IZIIS, Macedonia*
*Z. Milutinovic, IZIIS, Macedonia*
*T. Olumceva, IZIIS, Macedonia*
*G. Rockenschaub, WHO-EURO, Denmark*

Health facilities are essential for dealing with disaster, but are also highly vulnerable installations. Many factors contribute to the potential of external and internal disaster conditions in health facilities: 1) complexity; 2) occupancy; 3) critical supplies; 4) basic facilities (infrastructure); 5) heavy objects; 6) hazardous materials; and, 7) external dependence (security services and community aid). A reliable and comprehensive hospital vulnerability assessment can only be carried out taking into account all three main vulnerability categories: 1) structural; 2) nonstructural; and, 3) administrative / organizational vulnerability. New health facility integrated seismic vulnerability evaluation method (HVE method) is developed that can be used to: 1) perform preliminary (qualitative/quantitative) vulnerability assessment; 2) identify the possible weak elements in the facility and main vulnerability agents; and, 3) decide for prioritizations of the necessary further "in-depth" investigations. The HVE method main characteristics: 1) it is prepared to be suitable to hospital administrators (non-engineering profiles); 2) it is a hybrid method positioned mainly in the group of qualitative methods /rapid visual screening (RVS)/ combined with the screener's judgment; 3) it connects separate evaluation methods

for the three main vulnerability categories; 4) evaluation process is cascade depending on the seismicity level; 5) it corresponds to European distinctive features such as predominant health facility building typology, existing methods for vulnerability assessment and European macroseismic intensity scale (EMS-98) for determination of the possible seismic demand. In addition to the main purpose, the method itself or some of its parts can also be used for developing inventories of buildings for regional earthquake damage and loss impact assessment; developing inventories of health facilities for use in planning post-earthquake response activities; supporting building safety evaluation efforts and ranking health-care system rehabilitation needs; providing elements for society earthquake preparedness and developing building-specific seismic vulnerability information for other needs such as insurance rating.

### SEISMIC SYSTEM IDENTIFICATION OF THE VIENNA BASIN USING ARTIFICIAL MICRO EARTHQUAKES – ID 1321

*H. Wenzel, VCE, Austria*

The introduction of Eurocode 8 has brought considerable changes in the risk assessment in countries north of the Alps. In previous so called quiet zones earthquake is now the guiding design factor. For the huge stock of structures already existing the assessment of a realistic risk becomes essential and economically important.

The paper will describe the SEISMID method which stands for seismic system identification. Based on an artificial micro earthquake created by a defined falling weight, the response of the surrounding soil as well as the structures is monitored. Several sophisticated methodologies are combined in order to generate a valid risk map for the region as well as for very local circumstances. The results are microzonation for the city, which is of interest to the community, as well as detailed assessment of structures, which is of interest to the owners.

This huge initiative, started 2 years ago, produced considerable added value for the community and the population.

### AN ESTIMATION OF NATIONWIDE EARTHQUAKE DEATH TOLL - IN CASE OF JAPAN - – ID 1355

*Y. Ohta, Tono Research Instititute of Earthquake Science, Japan*
*N. Nojima, Gifu University, Japan*
*T. Nakashima, Aichi Shukutoku University, Japan*

We have been conducting a series of studies to develop a methodology to estimate the earthquake death toll, based on the field evidence that most deaths of inhabitants occur only under totally collapsed dwelling houses by seismic shaking. And, we have constructed a systematic equation set by which earthquake casualty features are described in good distinction between injury and death, and applications to the various administrative units of municipalities in Japan made clear its usefulness. Given essential data in the estimation are those on seismic hazard, stocks of dwelling houses with known vulnerability characteristics and population density of inhabitants and so on. In 2005, the Special Committee for Earthquake Research Promotion of Japan publicized nationwide probabilistic seismic hazard maps, totally of 12 cases with different probabilities as 2,5,10 and 39% in coming 50 years, through which one can refer ground surface seismic intensity values in any 1km by 1km segmental areas in all over Japan, amounting 300,000 units. This gives a good opportunity to extend our study area to the whole of Japan. Processes to estimate earthquake death toll in Japan and some of results are as follows; 1) All 12 seismic hazard maps were reduced to significant 4 maps after consideration of mutual resemblance. 2) Estimation of earthquake death toll was made using our new equation set which connects the relation, in probabilistic way, among seismic intensity, collapsing rates of dwelling houses and death rates. 3) A case with a probability of 2% brings a worst-case scenario with over 100,000 deaths and even in the case of a probability of 39% inhabitants to be killed are around 10,000. These figures strongly suggest us to facilitate prior and posterior countermeasures targeting drastic reduction of death toll under seismic shaking.

### SEISMIC RISK REDUCTION IN INDONESIA : IN THE PAST, TODAY AND FUTURE – ID 1489

*H. Z. Anwar, Indonesian Institute of Sciences, Indonesia*
*N. Okada, Disaster Prention Research Institute, Kyoto Univer, Japan*

Almost of all Indonesian archipelagoes are located at seismic active region, as one of the most active tectonic region in the world. Quite a distant of seismotectonic areas extending along western Sumatra Island to southern part Java and continue to the eastern Islands of Indonesian region. The strongest historical earthquake intensity were characterized by magnitude 9.0 occured at Aceh and North Sumatra region in 26 December 2004, which generated a deadliest tsunami.

The impact of earthquake disaster in Indonesia during three decades ago shows significant increases, the people killed, affected and also the house building damage. The increasing of population and the negative impact of the rapid development have a consequences to raise social, economic and physical vulnerability. In the past the disaster management is much concerted to the relief and response approach. However, since Indian Ocean Tsunami tragedy last 2004 the paradigm has changed to the more comprehensive disaster management approach. Currently, a considerable effort to reduce the impact of seismic hazard in Indonesia has been performed nationally and throughout international co-operation.

This paper describe an effort to improve the future disaster risk management system in Indonesia, which will be carried out through a collaborative research between Indonesian Institute of Sciences and Disaster Prevention Research Institute - Kyoto University. This research is committed to enhancing a comprehensive approach to disaster risk management, which assisting the implementation of mitigation program that will lessen the impact of natural disasters in Indonesia, which had been exponentially increased.

### TRANSFER OF TECHNOLOGY TO RURAL INDIA FOR SUBSTITUTING TRADITIONAL EARTHQUAKE RESISTANT CONSTRUCTION – ID 1585

*M. Mukherjee, iit roorkee, India*
*S. Mukherjee, independent researcher, India*

Rural India has strong building construction legacy for centuries using local materials and employing local manual-intensive techniques for earthquake-prone zones. Increasing requirement and change in use of space, dwindling supply of timbers and manpower unlike before, are some of the limitations of traditional construction; and pave way for radical entrance of new materials and techniques without any scope to develop understanding or technical expertise for the same. Instead of step-by-step substitution the new engineering materials and technologies are invading rural sustainable communities without any quality control. And community misses the cue that its magic power for providing safety owes to regulatory circumstance. Experiences from past earthquake open up this problem crudely. Loss of property and lives are more in case of ill-equipped engineered buildings constructed by non-technical people. In one district in the hills above Gölcük in Turkey in 1999, where 60 of the 814 reinforced-concrete, four-to-seven-story structures collapsed or were heavily damaged, only 4 of the 789 two-to-three-story traditional structures collapsed or had been heavily damaged. The problem does not lie with the technique, rather with transfer mechanisms. And social issues largely influence these. The present paper would look into this problem in three counts: · Why traditional construction technology is unable to satisfy people's need at present? · Why modern materials and technologies are not able to secure people's lives and property as they are claimed for so? And, · How to transfer modern technology safely to these rural communities so that they can have real safe environment and not an illusion? Behaviour of different buildings during earthquake would be studied and analysed. Impact of social factors is to be understood to identify the underlying issues. A search for roadmap for safe transfer of technology would be initiated.

## CS8: Secondary Earthquake Hazards: Tsunami, Landslide, Rock Fall, Liquefaction

Level 2

### SEISMIC LANDSLIDE HAZARD ASSESSMENT- OBSERVATIONAL AND ANALYTICAL APPROACHES – ID 105

*R. Chowdhury, University of Wollongong, Australia*
*S. Sarma, Imperial College, UK*
*P. Flentje, University of Wollongong, Australia*

This paper is concerned with seismic landslide hazard assessment, both site specific and regional. Recent studies and applications are cited in order to explore the role of empirical, analytical, probabilistic and observational approaches .The role of GIS-based methods and techniques for seismic landslide hazard mapping is highlighted. Comparison is made with the on-going developments with regard to methods for the assessment and management of rainfall-triggered landslides. In particular, attention is drawn to the hazard-consequence matrix approach. The development and use of a similar approach would be relevant to issues concerning risk management of seismic landslides. Attention is drawn to potentially important research directions The importance of seismic landslide hazard assessment is widely recognized. Significant progress has already been made in developing suitable methods of analysis for individual sites. These include methods of stability analysis based on the concept of limit equilibrium , more advanced approaches as well as sophisticated methods for estimating slope deformations. Because of the importance of uncertainties, suitable methods of probabilistic modeling have also been developed. GIS-based approaches have proved useful and effective for regional studies and for developing seismic landslide hazard maps. So far, only relatively simple analytical methods have been used as a basis for such mapping. The feasibility of using more sophisticated methods within a GIS-environment must be explored .The validation of hazard maps is facilitated by the use of reliable historical and observational data. Long-term surface and sub-surface monitoring can prove useful for further validation with the passage of time. Updating hazard maps after each significant earthquake will be feasible if such monitoring systems are in place. Existing systems may have been designed and installed for monitoring rainfall-triggered landslides. Therefore it is vitally important to reassess their suitability for slope performance under seismic conditions

### ASSESSMENT OF RELIABILITY OF DAMS AT ACTION OF FALLING-LANDSLIDE WAVES CAUSED BY EARTHQUAKES – ID 154

*O. Finagenov, The B.E. VEDENEEV VNIIG, Inc., Russian Federation*
*V. Glagovsky, The B.E. VEDENEEV VNIIG, Inc., Russian Federation*
*S. Shulman, The B.E. VEDENEEV VNIIG, Inc., Russian Federation*

A lot of problems is connected with the failure of stability of coastal slopes of mountain and submountain reservoirs resulting in falling-landslides that can expand on considerable areas. Moving masses of soils, rock, snow and ice entering the reservoirs generate the displacement waves - the so called impulse or "falling"(falling-landslide) waves which can reach a consider-able height and impact both on the coast and dam. In the extreme cases the waves of displacement may be very dangerous for settlements, economic objects located on the coasts of reservoirs, for navigation. The water overflow of such waves over a dam could result in its failure or flooding in the tail race with all subsequent eco-logical and social/economic consequences. The occurrence, parameters and expansion of the falling-landslide waves are defined by many factors which are connected with the degree of stability, geometrical and kinematic pa-rameters of potentially unstable masses as well as bathymetry characteristics of the reservoirs. The failure of potentially unstable masses occurs casually even when the motions are registered for a long period, and the probable failure of masses is perceived as a reliable event. Even if the failure of stability is predicted with great reliance, the questions connected with the establish-ment of geometrical parameters of a falling-landslide body always remain. To illustrate the probabilistic approach for prediction of falling-landslide waves in reser-voirs the solution of the problem within the framework of the approximate technique of calcula-tion of maximum height of falling waves in the design site using simple approximate formulas including only the basic design parameters have been considered.

### PROBABILISTIC ASSESSMENT OF RELIABILITY OF SOIL MASS BY LIQUEFACTION CRITERIA UNDER SEISMIC IMPACT – ID 155

*O. Finagenov, The B.E. VEDENEEV VNIIG, Inc., Russian Federation*

The occurrence and development of the superfluous pore pressure in soils resulting in liquefaction is defined by solution of the heterogeneous consolidation equation with the right-hand member depending on speed of volumetric deformations of a soil skeleton. In this case the superfluous pore pressure and the features of soil liquefaction are absent until the volumetric deformation of its skeleton is equal to zero. The assessment of local probability of liquefaction in each point of the structure and foundation is carried out by comparison of the acting and critical values of amplitudes of stresses and deformations in this point under dynamic impacts after solution of the appropriate static and dynamic tasks. In calculation of reliability of soil hydraulic structures the errors are possible due to inaccuracy of the accepted design model and finiteness of samples used for defining initial data. The real process is always more complicated than the accepted design model that results in so-called methodical errors. Another error is related with application of the initial statistical data in calculations. The result of the calculations is the point assessment (or assessment density) of the reliability. When the statistical samples, by which the initial parameters were defined, are too small, then, apart from the point assessment of the reliability, it is necessary to define also the accuracy of calculation of the point assessment, i.e. to calculate eventually the interval assessment of the reliability.

### INVESTIGATION ON THE LIQUEFACTION OCCURRED IN A CLAYEY SANDY SOIL DURING THE CHANGUREH EARTHQUAKE – ID 389

*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*
*M. Ghahremani, University of Tehran, Iran (Islamic Republic Of)*
*K. Konagai, University of Tokyo, Japan*

An intense earthquake (MW = 6.4) occurred in western Iran, about 225 km west of Tehran at 7:28 local time, June 22, 2002. The affected region is located in the west of Takestan-Hamedan road along an east-west oriented valley in the west of the Abegarm village. Surface soil in this area is mostly clay; however, clear traces of sand boiling, softening of soil, and consequent deformations were observed particularly in Hessar village. Some soil samples were prepared throughout an excavated pit from a depth of 2 m, the depth of the liquefied layer. The preliminary tests showed that the soil has a liquid limit of 38, a plasticity index of 18, and a $<$ No. 200 fraction of 44%. These index characteristics would indicate a nonliquefiable soil according to the commonly used criteria recommended by Seed and Idriss (1982). Analysis of cyclic triaxial test data suggests that the clayey sand deposit likely developed high residual excess pore pressures and significant shear strains during the earthquake and thus likely contributed to the observed lateral deformations. This observation showed that the case of Changureh earthquake is one of the very rare evidences that liquefaction could occur in soils with this much high clay content. In this paper, different cases of observed liquefaction and consequent geotechnical

phenomena are presented. Moreover, the results of laboratory tests on reconstituted samples are presented to prove how a soil with 44% of clay content could be liquefied. The field evidences and laboratory data show that commonly used criteria for identifying "liquefiable" clayey soils should be applied with caution and should not be indiscriminately viewed as a substitute for detailed laboratory and in situ testing of low plasticity fine-grained soils.

### MICROZONATION STUDIES BASED ON SOIL LIQUEFACTION: YALOVA CITY (TURKEY) – ID 435

*F. Ozcep, Istanbul University, Turkey*
*H. Zarif, stanbul University, Turkey*

Over the last 35 years, tremendous effort has been expended to understand the mechanics of liquefaction. Understanding liquefaction behavior begins with understanding that liquefaction, in all its forms, is the frictional behavior of cohesionless soils under elevated porewater pressure during rapid loading.Soil liquefaction is a natural event in which the strength and stiffness of a soil is reduced by earthquake vibrations or other dynamic loading. As it is known, liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. Before the dynamic loading , the water pressure is relatively low. However, earthquake vibrations can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. Microzonation is the identification of separate individual areas having different potentials for hazardous earthquake effects. In the last decades seismic microzonation became one of the fundamental aspects in engineering seismology. The traditional method for evaluating soil liquefaction assesses the liquefaction potential based on the safety factor it produces. One of these methods based on Cyclic Stress Approach. In this method, safety factor is defined as CRR / CSR. CRR is Cyclic resistance ratio that reperesents soil liquefaction susceptibility, and CSR is cyclic stress ratio that represents earthquake effect. In this study, for several design magnitudes and accelerations, the soil liquefaction maps, based on field data (N60 and Vs data), were produced for microzonation aims in Yalova City (Turkey)

### PERMEABILITY CONTRAST EFFECTS ON LIQUEFIABLE GROUND RESPONSE WITH BARRIER LAYER – ID 473

*M. Seid-Karbasi, University of British Columbia, Canada*
*P. Byrne, University of British Columbia, Canada*

The effects of liquefaction on foundations and earth structures e.g. dams and lifelines, continue to produce large economic and human losses in many areas of the world as a result of earthquakes. Our understanding of the phenomenon has improved dramatically due to observations from past earthquakes, as well as numerous experimental studies (element testing and physical models) and development of numerical procedures. The classic examples of liquefaction-induced failure are the Lower San Fernando dam in US, and Mochikoshi tailings dams in Japan which failed during 1971 and 1978 earthquakes respectively. In the first case, the dam experienced flow failure about 1 min after the main shock and in the second case, one dam failed about 24 hrs after the event. Also, a number of case histories indicate that lateral spreads and flow slides have taken place in coastal and river areas. Movements may exceed several meters even in very gentle slopes. More interestingly, these failures have occurred not only during, but also after shaking. These large movements are mainly driven by gravity, although initially triggered by seismic liquefaction. Recent investigations has shown that the presence of a sub-layer with relatively lower permeability is responsible for such behavior. A low permeability layer or layers form a barrier that impedes upward flow of water associated with liquefaction during and after earthquake. This results in skeleton expansion in a zone beneath the barrier base, and a post-liquefaction strength loss that can lead to flow failure. This mechanism explains the low back-calculated strengths and post-shaking failures observed in case histories. In this study a coupled stress-flow analysis is applied to an infinite slope, and it is shown that the mechanism is controlled by permeability contrast between liquefiable soil and the barrier, and cause lateral displacements to increase as the permeability contrast becomes higher.

### NUMERICAL AND EXPERIMENTAL STUDY ON SEISMIC PERFORMANCE OF GRAVITY TYPE QUAY WALL – ID 498

*A. Arablouei, Sahand University of technology, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, Tehran University, Iran (Islamic Republic Of)*
*A. R. M.gharabaghi, Sahand University of Technology, Iran (Islamic Republic Of)*

Serious damages to the gravity type quay walls during some recent earthquakes, particularly the 1995 Hanshin-Awaji earthquake, have shown the vulnerability of this type structures under earthquake hazard. Design of quay walls is conventionally based on the stability analysis and controlling the factor of safety against different types of failures. Extension of this method to the seismic design of quay walls and assuming an equivalent static load is the base of the most existing design codes. Performance-based design is an emerging methodology, which was born from the lessons learned from earthquakes in 1990s. The goal is to overcome the limitations in conventional seismic design. In the performance-based design method, lateral spreading of the saturated backfill and foundation soil along with the effect of the quay wall as the supporting structure should be clearly understood to design a more reliable structure. A series of shaking table tests were conducted to study the seismic performance of a gravity type quay wall constructed on loose saturated sand. Using a nonlinear finite difference program, a numerical study of shaking table tests is carried out. In this paper, the shaking table tests and formulation of employed computational code are described and the results of numerical simulation are compared to the measured records. The results demonstrate that the trend and magnitude of vertical and horizontal displacement of quay wall appears to be predicted reasonably. The overall tendency is to overpredict the horizontal movement but the vertical movement is underpredicted.

### TRANSNATIONAL EFFECTS OF LARGE EARTHQUAKES – ID 544

*D. Niyazov, Earthquake Engineering and Seismology, Tajikistan*

Natural disasters are most dangerous for normal development of economy and society of Tajikistan and other states of Central Asian region. The territory of Tajikistan is completely located in high seismic dangerous zone. Destructive earthquakes, which have occurred in territory of Tajikistan in XX century, demonstrate the high risk and vulnerability for the most populous areas and cities in the region. Natural disasters such as earthquakes, landslips, landslides, rock falls and other extreme situations bring potentially huge hazard for economy and society. The majority of strong and moderate magnitude earthquakes will become the trigger mechanism for landslides and landslips in Tajikistan. These secondary consequences of the earthquakes carry out the heaviest human and material damage than main quakes. Khait earthquake of July 10, 1949 is a bright example of significant defeat of mountain areas of Tajikistan by landslides and landslips. Khait earthquake is considered as one of the most catastrophic seismic events for the last hundred years in Central Asia. More than 150 houses have been suffered and almost 30 000 man killed. The high-mountainous lakes such as Sarez in Pamir and the largest artificial reservoirs such as Nurek, Kharakhum and others are of a sufficient threat too. Break of dams, wasted lakes, and artificial water reservoirs can result catastrophic flooding on extensive zones throughout Central Asia. Of the main challenges are more than 120 large the mining enterprises objects in Central Asia region, where intensive extraction and processing of a deposits in past was organized. The waste from this enterprises contents different dangerous chemical elements and so even not so strong earthquakes can trigger large-scale technological catastrophe, hundreds times exceeding earthquake direct damage. The Central Asian countries

present high degree of vulnerability at natural and technological disasters and it's extremely important to unite efforts to sustain so dangerous natural phenomenon as earthquakes.

### VULNERABILITY FUNCTIONS FOR TSUNAMI LOSS ESTIMATION – ID 1121

*N. Peiris, Arup, UK*

The Indian Ocean tsunami of December 26, 2004 that followed the magnitude 9.2Mw Sumatra Earthquake revealed the vulnerability of the coastal regions of the countries surrounding the Indian Ocean. The tsunami resulted in over 200,000 fatalities and damage to a large number of structures in the affected countries, leading to widespread economic losses.

Sri Lanka with a large coastal community about 2000km away from the epicenter of the Sumatra Earthquake was one of worst affected countries from the ensuing tsunami. This paper presents vulnerability functions developed for residential and non-residential structures using the data available for the coastal areas of Sri Lanka and describes how the functions should be applied within a tsunami loss estimation calculation. Vulnerability functions have been developed for various types of buildings commonly found in the Sri Lankan coastal areas, e.g. unreinforced masonry, confined masonry, reinforced concrete with masonry infill, etc. The vulnerability functions were found to be dependent on the tsunami inundation distance, water height and estimated velocities of flow of water. In addition functions have been developed for the determination of casualties using their relationship with the building damage data.

The data sets for this study were based on the field missions conducted by the author independently and as part of the Earthquake Engineering Field Investigation Team (EEFIT) and data available in the public domain. It is anticipated that the vulnerability functions developed here could be extended to other elements under risk e.g. infrastructure, ports and other facilities, and the methodology could be applied in other countries at risk from tsunami inundation, such as those surrounding the Mediterranean and other parts of Europe.

### TWO-WAY INFORMATION SUPPORT SYSTEM BETWEEN RESIDENTS AND FIRE HEADQUARTER IN CASE OF LANDSLIDE DISASTERS – ID 1200

*T. Mizuta, Akita National College of Technology, Japan*
*K. Asano, Akita Prefectural University, Japan*

Objective in this study is implementation of two-way information support system between residents, Fire Headquarters and local government to prevent and reduce damage from landslide disaster. First, we develop a highly qualified assessment method of slope failure potential by reflecting mutual effect between regional factors such as heavy rainfalls and snow melt water, and unexpected factors in case of earthquake. Second, we develop a system that Fire Headquarters can specify the disaster location by extracting area descriptions from reporter, in case of receiving emergency call without location specified. Third, we build total system that supports following situations to be possible: Residents, Fire Headquarters and local government share disaster information, that's likely been a fragment; local government confirms and reconstructs the critical location; residents is able to take appropriate and independent action in alert condition; and Fire Headquarters is supported to take quick action in a time of disaster.

### ASSESSMENT MODEL FOR THE LIQUEFACTION PROBABILITY AND ASSOCIATED DAMAGES – ID 1239

*F. K. Huang, Tamkang University, Taiwan*
*G. Wang, Chaoyang University of Technology, Taiwan*

This paper presents a new simplified method for assessing the liquefaction resistance of soils based on the standard penetration test (SPT), and the probabilistic model for evaluating liquefaction potential and associated damages. The new approach is developed using a database consisting of 655 field liquefaction performance cases at sites where SPT had been conducted. This database is first used to analyze the liquefaction probability by logistic regression with parametric forms of known simplified procedures for soil liquefaction evaluation, including Seed, T-Y, and NJRA methods. The new simplified method is thus obtained using the results of logistic regression and the method of information theory. Relationships between calculated factors of safety and probability of liquefaction are then established by logistic mapping approach and Bayesian mapping approach for all simplified method. Based on these results and studies from Iwasaki et al. (1982), damages index including reduction factor of soil (DE), liquefaction potential index (IL) are proposed for the new simplified method. Design chart for soil improvement based on probability is also prepared. The newly developed model provides a basis for risk-based evaluation of liquefaction potential and damages. It is worthwhile to apply these concepts and results to engineering community.

### AN INTEGRATED GIS TOOL FOR SEISMIC-INDUCED LANDSLIDE HAZARD MAPPING – ID 1365

*M. Sakellariou, NTUA, Greece*
*M. Ferentinou, NTUA, Greece*
*S. Charalambous, NTUA, Greece*

Seismic triggered landslides present a major hazard in many regions and are among the most important natural hazards that cause serious casualties, fatalities and destruction to the natural and built environment. An integrated tool was developed in a GIS environment aiming to produce landslide hazard models for earthquake–induced landslides. The modes of failure implemented in the tool are the planar, the circular, the wedge and the rockfall. These hazard models usually provide a preliminary indication of the zone of influence of earthquake events of certain magnitude, considering the certain geological formations that are more susceptible to seismic-triggered landslide events and the type of failure that might occur. This particular model takes into account the local ground conditions, slope hydrology, the landscape of the study area, the type of failure, the magnitude of the seismic event and the epicenter distance in order to estimate the influence zone. The problem of slope stability is considered through the examination of the factors leading to failure occurrence. Computational tools were used in order to estimate safety factor and judge upon the influence of the geotechnical and geometrical variables involved. The estimation of permanent slope displacements induced by seismic events followed Newmark's model, and the methodology of permanent displacements proposed by Ambraseys and Menu (1988) and Ambraseys and Srbulov (1995). Moreover, this integrated tool is expanded in order to simulate the 3-D rockfall trajectories. The parameters implicated in the model are the topography of the study area, the friction characteristics of the ground, the magnitude and direction of the initial velocity, and the energy damping coefficients.

### HAZARD MAPPING OF EARTHQUAKE TRIGGERED LANDSLIDES – ID 1405

*K. Ratzinger, VCE Holding, Austria*
*B. Neuhäuser, VCE Holding, Austria*

Landslides are among the most distributed earthquake induces secondary effects and are causing huge damage to settlements, infrastructure and human life.

A time and cost effective method to identify high risk areas and landslide prone areas is the combination of remote sensing data and geologic, tectonic information. This method can be used world wide since there are many sources of remote sensing data today. They can help to assess the potential further risk sites and contribute to a better understanding of processes triggering landslides. The results from remote sensing analysis can be further integrated in a GIS-based model for landslide susceptibility mapping.

Several investigations on different test sites have been performed during the OASYS (Integrated Optimization of Landslide Alert Systems, EVG1-2001-00061) project that considered the support pro-

vided by spatial databases for the delineation of potential natural hazard sites in the different test areas. The goal was to develop a small scale approach combining analysis of optical (LANDSAT ETM) and SAR intensity (ERS-1/2) remote sensing data with results from differential SAR interferometry in a GIS environment to assess the potential for landslide hazard on a regional basis.

Special emphasis was put on the seismicity of concerned areas. Structural features visible on satellite imageries area were mapped to investigate the tectonic setting and to detect surface traces of fracture and fault zones. Special attention is focused on the detection of active, neotectonic features and to find and map not yet known fault segments and structures. Fault segments, their bends and intersection are more apt to concentrate stress and amplify seismic shock and, thus, enhance landslide risk. The result from the satellite image analysis was used in GIS-based model for assessing the landslides susceptibility. Historical earthquakes as well as the actual tectonic situation influencing the damage intensity were integrated in the model.

### SEISMICALLY TRIGGERED LANDSLIDES : FROM FIELD OBSERVATION TO HAZARD ASSESSMENT – ID 1650

*H. B. Havenith, ETH Zurich, Switzerland*

After major earthquakes, extensive field surveys have been organized to observe and map triggered mass movements. Many of these observations are known from the Americas and Japan. Examples include the surveys carried out by after the Peru, 1970, the Guatemala earthquake, 1976, the Loma Prieta, 1989, the Northridge, 1994 or the El Salvador, 2001 earthquakes; in Japan, after the Kobe, 1995 and the 2004 Niigta events. These surveys principally included geological and geomorphological field works and interpretation of aerial photographs. Surprisingly little means had been spent on advanced geophysical and geotechnical investigations, analyses of satellite imagery, and the understanding of the triggering processes through computational back-analyses (numerical modelling). Further, it can be noticed that advances in seismic hazard computation, seismic microzonation and in general landslide susceptibility mapping have not yet been (or are poorly) implemented in the assessment of seismic landslide hazard. In this paper, we shortly present the state-of-the-art in assessing seismic and landslide hazard, respectively; then, we will outline possible techniques of how connecting both approaches. Further, it will be shown how field observations, investigations and modelling could be better implemented in the hazard assessment. As application of the proposed approach we will present an overview of our recent work done in Kyrgyzstan, Central Asia. This work is based on the efficient combination of investigation and modelling : what is needed to back-analyse and simulate seismic ground motions, their effect on slope stability under dry and water-saturated conditions – in a rock and soft sediment environment. The second step is to incorporate the modelling results in the computation of landslide susceptibility or, better, landslide prediction maps. In particular we will propose a methodology to use both existing events and modelling results for the verification of the hazard map.

### IMPACT OF GROUNDWATER FLOW ON THE SEISMIC TRIGGERING OF LANDSLIDES : A NUMERICAL ANALYSIS – ID 1668

*C. Bourdeau, ITASCA Consultants, France*
*H. B. Havenith, ETH, Switzerland*

The destructive impact of earthquakes is often strongly enhanced by the triggering of landslides. This phenomenon is one of the major concerns of the Central Asian Republic of Kyrgyzstan, a country characterized by a high seismicity and rough topography particularly prone to landslides. In the frame of recent studies, several researchers focused their interest on the seismic initiation of slope failures in the Southern Kyrgyz Provinces surrounding the Fergana valley. One of the sites investigated is located in the region of Gulcha close to the village of Kainama where many landslides develop every year. One of them, a loess slide, was triggered in 2004 by a combination of small-magnitude-earthquakes and heavy rain falls; it killed 33 people. This work is based on data provided by a field survey carried out in 2005 by Swiss, Kyrgyz and Belgian teams on a (possibly unstable) slope close to the loess slide: topographical information, geological structure, local ground-motion amplifications and ground resistivities. Through numerical simulations with FLAC 2D, we assessed the sliding potential of a (possibly unstable) slope close to the loess slide. The seismic shaking was considered as the trigger but we also took into account groundwater flow within the slope and the co-seismic pore pressure generation requiring a dynamic hydro-mechanical analysis. In this work, we will show the detailed results of this case-study: comparisons between the simulated and measured elastic seismic ground response, the transition from elastic to plastic deformation, the development of catastrophic failure and outline the influence of seismically induced pore pressure variations on the triggering of failure.

### DISCRIMINATION OF THE NATURE OF TSUNAMI SOURCES (EARTHQUAKE VS. LANDSLIDE) IN EASTERN SICILY USING HISTORICAL DATA – ID 1929

*F. Gerardi, Dipartimento di Scienze geologiche-Uni Ct, Italy*
*P. M. De Martini, INGV, Italy*
*M. S. Barbano, Dipartimento di Scienze geologiche-Uni Ct, Italy*
*D. Pantosti, INGV, Italy*

Italy has numerous data on natural disasters in the past two millennia. So it offers a unique possibility to experiment and test new approaches for understanding these phenomena. In particular, eastern Sicily has been affected by the largest earthquakes (Mw up to 7.4) ever occurred in Italy. The Messina Straits contains the epicentral area of the 1908 earthquake and south-eastern Sicily was largely destroyed by the 1169 and 1693 earthquakes, although the identification of their sources, either offshore or inland, is still debated. As described in the historical reports, devastating tsunamis followed these earthquakes. Through detailed analyses of coeval accounts, we compiled a database storing information on the effects of tsunamis. Due to the uncertainties in the location of these earthquake sources in eastern Sicily a debate on the origin of the tsunamis (seismic dislocation vs. landslide) has recently started. On the basis of the method proposed by Okal and Synolakis (2004), we try to contribute to this debate by using historical run-up amplitudes in the near-field. Following this approach, we fit empirically the run-up $\xi(y)$ in their formula: $\xi(y) = b / \{[(y-c)/a]2 +1\}$ The values "a" and "b" are used to calculate the parameter I2 = b/a, the ratio of the maximum run-up to its lateral extent along beach. I2 discriminates the source nature and for the 1908 run-up data, it suggests that the tsunami source is a seismic dislocation. Moreover, we consider the parameter I1 = $b/\Delta u$, the ratio of the maximum run-up to the amplitude of seismic slip on the fault. For the 1908 earthquake the combined values I1 and I2 confirm that the 1908 run-up distribution is compatible with a tsunami generated by an earthquake. Stimulated by this result, we have applied the same approach to other historical tsunamis of eastern Sicily.

### ANALYSIS OF TSUNAMI RISK APPLIED TO A REACH OF THE LIGURIAN COAST – ID 2035

*F. Bacino, University of Genova, Italy*
*P. Poggi, University of Genova, Italy*
*T. Cosso, DIMSET-University of Genova, Italy*
*C. Eva, DIPTERIS-University of Genova, Italy*
*B. Federici, DIMSET-University of Genova, Italy*
*D. Sguerso, DIMSET-University of Genova, Italy*
*S. Solarino, INGV, Italy*

In the last 1000 years, 71 tsunamis occurred in Italy, 14 of which interested the western part of Liguria coast and the neighbouring French coast. Recent studies confirmed that these episodes may repeat since some of the seismogenic structures of the Ligurian Sea could be responsible for tsunamis; moreover, the Ligurian coast has experienced several times in the past anomalous increase of the marine wave due to the propagation of

T waves; therefore it is of paramount importance to forecast the consequences of these phenomena and their impact on the coast. We have predisposed a procedure to realize Tsunami Inundation Maps starting from offshore wave height, Digital Terrain Model and Land Use Cartography (or aerial photographs to classify if Land Use Cartography is not available) through the software GIS open source GRASS (see Bacino et al., session CS6). As a test, we have applied the whole procedure to a reach of the Ligurian coast, characterized by either gentle slope beaches without protection, hence more exposed to risk, and rock cliffs less liable to damage. To overcome the complexity of the phenomena, we have introduced simplifications about the structure of the wave coming in the coast and the determination of the wave run-up, though we took into account the local slope representative of the coastal zone. Then we have simulated the inundation considering the terrain roughness due to vegetation and settlements. In this contribution, we discuss the choice of the input parameters and the reliability of the findings. In fact, even if based on a simplified approach, the results that we obtained are realistic: values of ashore wave height ranging from 0.5 to 2.5 m, comparable with what actually expected in the Ligurian sea, can lead to inundations of about 50 m, which are not negligible.

## ES 1: Geotechnical Engineering

Level-1

### EARTHQUAKE DISPLACEMENTS SETTING FOR CALCULATING STRUCTURES AND BUILDING EARTHQUAKE SCALES – ID 32

*A. Uzdin, Petersburg Transport University, Russian Federation*
*L. Dmitrovskaya, Petersburg Transport University, Russian Federation*

Displacements of the original ground are the major characteristics of seismic impact. They determine seismic stability of multi-supported and long-period structures structures. Though displacement setting is necessary, there is no proper information about design displacements in guide-lines. The available data allow to assert, that actual original ground displacements can be quite considerable. These displacements determine seismic stability of the majority of multi-supported structures with long spans. However, seismic stability of constructions should be estimated taking into account a complex nature of seismic displacement. An impact of an impulse on a homogeneous environment causes the running wave. At the wave front there arises a break of displacement, and behind it the environment receives residual displacement. On its way the wave meets various obstacles resulting in it diffraction and occurrence of additional waves, caused by natural vibrations of these obstacles. The stated reasons allow to regard the seismic soil movement as the sum of the running wave and incoherence excitations of the original ground points. Such approach to displacement analysis is considered in the paper. Each of the sum components influences structures behavior in its own way. Therefore, estimating earthquake displacements as a whole is absolutely useless for the engineer. Structures calculations require dividing displacements into the running wave and incoherence points excitations. The first constituent is characterized by big, sometimes more than one meter displacements and relatively small accelerations. These displacements are distributed on a big area and are dangerous only for especially extended or flexible constructions. Mutual displacements of the construction supports at the passage of this wave are important, but usually constitute only 5-10% of the absolute displacement of the soil basis. The second component has much smaller displacements. They do not usually exceed 10-15 cm and are important for calculation of usual structures.

### MODELLING THE SEISMIC RESPONSE OF CANTILEVER EARTH-RETAINING WALLS USING DIANA – ID 74

*P. Rajeev, ROSE School, Italy*
*P. E. Pinto, Università degli Studi di Roma "La Sapienza", Italy*
*C. Lai, EUCENTRE, Italy*
*P. Franchin, Università degli Studi di Roma "La Sapienza", Italy*

In current engineering practice the design methods for earth retaining walls under seismic conditions are mostly empirical. Dynamic earth pressures are calculated assuming prescribed seismic coefficient acting in the horizontal and vertical directions using the concept of Mononobe-Okabe method. A research investigation has been undertaken to determine the dynamically-induced lateral earth pressures on the stem portion of a concrete, flexible cantilever retaining wall with cohesionless backfill. A series of finite element numerical analyses have been performed using DIANA. Particular attention has been devoted to ground excitation, modeling of the wall-soil interface and soil constitutive modeling. The results obtained with DIANA have been compared through a series of benchmark tests with those determined using simplified techniques for computing dynamic earth pressure, co-seismic and post-seismic wall displacements.

### EVALUATION OF SOIL STRUCTURE INTERACTION BY USING NEURAL NETWORK METHODOLOGY – ID 92

*O. Sariyar, Istanbul Technical University, Turkey*
*D. Ural, Istanbul Technical University, Turkey*

The research presented involves the use of artificial intelligence for soil-structure interaction problems. Previous atificial intelligence applications in geotechnical earthquake engineering included liquefaction analysis, attenuation relationships, and in this paper, the complex problem of soil-structure interaction is presented. In this study, 58 earthquake, structure, and soil properties from local sites in California are used. In the Artificial Intelligence approach, two Neural Network architectures are utilized. These approaches include the Back Propagation Neural Network architecture (BPNN) and General Regression Neural Network approach (GRNN) architecture. The analysis incorporated 21 input parameters and 4 output parameters. One of the four output parameters is whether Soil-Structure Interaction effects can be neglected The remaining output parameters include the soil-to-structure rigidity ratio, period lengthening, and foundation damping. The applicability of artificial intelligence methods for soil structure interaction, and a sensitivity study for the 21 earthquake, soil and structure data parameters will be presented.

### SOIL PILE GROUP AND SUPERSTRUCTURE INTERACTION UNDER SEISMIC LOADING – ID 96

*R. Taherzadeh, Ecole Centrale Paris, France*
*D. Clouteau, Ecole Centrale Paris, France*

There have been many publications related to the dynamic interaction between a pile group and the soil represented by an elastic half space. In all of these studies (Wolf et Arx.(1978), Nogami & Novak (1979), Kaynia & Kausel (1982)) the influence of certain parameters of the soil and the piles such as, the flexibility ratio of soil and pile, spacing and the number of piles have been investigated. In fact only a few attempts have been made to study the effects of cap foundation on the dynamic behavior of the structure and pile group. The objective of this work is to study the 3 dimensional dynamic behavior of pile groups in layered semi-infinite media and to investigate the effects of the flexibility of the cap, cap-soil contact and liquefiability of the soil to the response of pile group and structure. This study is carried out with the numerical FEM-BEM coupling technique and the results are compared with simplified models such as an equivalent embedded foundation the method of interact factors. In a second step the complete structural response is compared with the approximate method consisting of replacing the dynamic impedance of the foundation by equivalent springs and dashpots.

### DYNAMIC CHARACTERIZATION OF EMBANKMENT WITH INCLINED BASE GROUND UNDER STRONG EARTHQUAKE MOTION – ID 99

*L. Li, Nippon Koei Co., Ltd., Japan*
*Y. Hata, Nippon Koei Co., Ltd., Japan*

During the recent and past major earthquakes in Japan, such as Niigataken-chuetsu Earthquake of 2004, Miyagiken-oki Earthquake of 2003, Hyogoken-nanbu Earthquake of 1995, and Kushiro-oki Earthquake of 1993, larger deformation and slip failure damages repeatedly occurred in the earth embankments with inclined base grounds for railway and highway networks. To improve the safety of such traffic and transportation networks during large earthquake disasters, the characterization of seismic performance of the earth embankments for such lifeline systems is rising as an important subject to establish a reasonable method for evaluating the dynamic behavior of such earth structures. In order to clarify the effects of the formation of base grounds on the dynamic behavior of the earth embankments and their failure mechanism under strong earthquake motion, a series of dynamic centrifuge model tests by inputting earthquake motion records was conducted to investigate the seismic response and the earthquake induced permanent deformations of the earth embankments with inclined base grounds. The effects of the acceleration response on the deformation of the embankments were mainly focused. The test results show that the dynamic behavior of the embankments with inclined base grounds was quiet different from that of the embankment with horizontal base ground. To comprehensively understand the failure mechanisms of the earth embankments, the test results were also validated through a series of numerical analyses by considering the effects of both the horizontal and vertical acceleration response on the permanent deformation of the embankments. This paper introduces the details of the test program, the numerical model together with the test and analytical results.

### POST EARTHQUAKE DEBRIS : GENERATION AND MANAGEMENT – ID 157

*R. Sarkar, G.B. Pant Polytechnic, Okhla, India*

Earthquakes strike with varying degrees of severity and pose both short and long-term challenges to public service providers. As a result of an earthquake, large quantities of the building stock and infrastructure are often damaged beyond economic repair and require demolition with subsequent removal of debris. The management of this debris, as well as the waste generated during the reconstruction works, can place significant challenges on the national and local capacities. These wastes not only create significant health problems and a very unpleasant living environment if not disposed of safely and appropriately but also can subsequently impose economical burdens on the reconstruction phase. In practice, most of the debris may be either disposed of at landfill sites or reused as materials for construction. Therefore the debris clearance operation should focus on the geotechnical engineering approach as an important post-disaster issue to control the quality of the incoming flow of potential soil materials. In this paper the importance of an emergency management perspective in this geotechnical approach that takes into account the different criteria related to the operation execution is proposed by highlighting the key issues concerning the handling of the construction and demolition wastes following an earthquake.

### HAZARDOUS CONDITIONS OF COLLAPSIBLE LOESS SOIL IN SEISMIC ACTIVE AREAS – ID 158

*N. Mavlyanova, Seismology, Uzbekistan*

The territory of Republic of Uzbekistan subdivided into two large regions the lowland (Turan plain) and mountain zone (Western Tian-Shan). As a result of historical development the basic part of the population of the country lives in a foothill zones and in intermountain hollows. People choose the place for life and built cities there where were sources of water and the fertile ground. In conditions of Uzbekistan this is the high seismic zone covers by loess soil. Now the 93 % of the population of the republic lives in this zone. Loess soils cover a large area of the territory of Uzbekistan and it is one of the major problem soils. The loess soil has a potential to collapse which caused severe settlement problems for many structures founded upon it. By comparison of the map of seismic zoning to a map of distribution of loess soils it is easy to be convinced that the territory of the majority of dangerous seismic areas are covering by collapsible loess soils with significant thickness (50-100 m). Various types of ground failures such as subsidence, landslides and liquefaction are associated with moderate-size or large earthquakes occurred in Uzbekistan. For studying of seismic properties of loess soil the field researches near to city of Tashkent on loess massive with capacity of 40 m were conducted. The change of engineering - geological and seismic properties of loess soils after wetting were determined. The analysis of results of the conducted researches has shown that after artificial wetting of loess soils all physical - mechanical properties were changing. With increase of wetting the porosity and distribution of seismic waves decreases. All this reduces the seismic stability of loess soils in the base of constructions.

### GROUND VIBRATION DUE TO A TRAIN MOVING IN UNDERGROUND TUNNELS – ID 199

*J. F. Chai, Nat. Center for Research on Earthquake Engineering, Taiwan*
*T. J. Teng, Nat. Center for Research on Earthquake Engineering, Taiwan*

The objective of this paper is to determine the ground vibration generated by a train moving in underground tunnels. Firstly, the tunnel is assumed to be an infinite hollow cylindrical waveguide located in an infinite domain. Under the consideration of the gaps between adjacent slabs and the constraint from equal-spacing fasteners, the vertical force loaded by the moving train is modeled by a periodical source time function. Consequently, the induced vibration at any specified observation point on the inner wall of the embedded waveguide can be determined on the basis of the T-matrix method. On the other hand, thanks to the Taipei Rapid Transit Corporation for the permission of an in-situ test, the train-induced vibration on the inner wall of underground tunnels was measured to verify the proposed periodical source time function and further, to identify the associated loading parameters. It can be found that the numerical results, both the waveform in time domain and the Fourier spectrum in frequency domain, are in good agreement with the measured signals. Based on the proposed source time function as well as the identified loading parameters, the train-induced wave field in the surrounding soil can be also determined. Moreover, in this paper, the site effect is considered by modeling the soil layers as a layered half-space, and the aforementioned wave field is recognized as the perturbation source within the upper soil layer. Then, under the boundary conditions of continuity at the interface and traction free on the ground surface, the induced ground vibration can be determined by means of the transmission and reflection coefficients of scattered waves at boundaries. It is noted that the simulated ground acceleration can be applied to a time history analysis to evaluate the structural vibration affected by the trains moving in underground tunnels.

### DESIGN OF RIGID RETAINING WALLS IN SEISMIC AREAS – ID 283

*S. Prakash, UMR, United States*
*V. Puri, SIU, United States*
*Y. Wu, Geotechnology, United States*

Rigid retaining walls have been observed to undergo significant displacements during several past earthquakes. Several investigators have developed 1-D and 2-D models to predict displacements. A critical review of the state of the art shows that these models may not predict realistic displacements.

A new 2-D model, which considers strain dependent soil stiffness and material damping, sliding and rocking motions, and practical field water conditions behind the wall as per Eurocode has been developed. This model represents a considerable advance over the

existing solutions. The model considers the permissible displacement of the wall . It has been validated on typical centrifuge models. Further validation on full scale prototype is included in this paper.

A detailed analysis of 21-backfill and foundation soil combinations has been used in a parametric study of walls of different heights and as per Eurocode for 3-different ground motions, ie El Centro, Loma Prieta, and Northridge. The effect of inclination of the wall face in contact with the backfill on the development of dynamic active pressure and its displacement has been investigated in detail. It is shown that walls inclined towards the fill by as little as 5 degrees experience simlar displacements under earthquake as the vertical walls, but resulting in savings on material of the order of about 10 percent.

### A STUDY ON EMBEDMENT EFFECT USING COMPRESSION ONLY ELEMENT IN SOIL-STRUCTURE INTERACTION ANALYSIS – ID 289

*Y. S. Jang, KOPEC, Korea, Republic Of*

In SSI analysis, there can be uncertainties in bonding and de-bonding phenomena between the embeded structural part and the side soil. According to ASCE Standard 4-98, one method to address this concern is to assume no connectivity between structure and side soil over the upper half of the embedment or 20 ft, whichever is less. Per the ASCE Standard 4-98 recommended procedure, the connectivities are removed between the structure and the side soil. This may be good for design of the structure, but real phenomenon of contact between structure and side soil in SSI analysis can be better represented by using the compression only element(spring), instead of removing the connectivity between the structure and the side soil. However the compression only spring can't be used in frequency domain analysis because the element has a critical defect. In frequency domain analysis, the impedance of the compression only spring between the structure and the side soil can not be calculated. Therefore, two-step analysis concept is recommended herein for application of the compression only spring ; Step 1 : Preliminary SSI analyses to determine the foundation motion using SASSI. Step 2 : Structure response analysis using the compression only spring and the foundation motion calculated in step 1. As an example application to the Nuclear Power Plant, analyses of bonding and de-bonding problem, as used in SSI analysis of NI of APR1400 (Advanced Power Reactor 1400) was selected. This study was performed as part of the parametric analyses for the APR1400 seismic analyses to address the concern of the potential embedment effect on the in-structure response spectra due to connectivity between the structure and the side soil. The results of each analysis are compared and evaluated. The various analysis cases which are used in this study are 1) no separation, 2) ASCE Standard 4-98 recommended procedure, and 3) the compression only spring method.

### POSSIBILITY OF SOFTWARE APPLICABILITY FOR DYNAMIC PROBLEM MODELLING – ID 320

*B. Lunacek, VSB-Technical University of Ostrava, Czech Republic*
*E. Hrubesova, VSB-Technical University of Ostrava, Czech Republic*
*M. Lednicka, VSB-Technical University of Ostrava, Czech Republic*
*Z. Kalab, Institute of Geonics, Czech Republic*
*R. Korinek, VSB-Technical University of Ostrava, Czech Republic*

Software system Plaxis which is possible to be used for creation of computing models of seismic generation will be specified in this article. Principles of dynamic analysis can be divided into two basic types; the source of dynamic load is either one-point source of vibrations or an earthquake. For an example the influence of quarry blasts (brown coal quarry in Northern Bohemia) was modelled with use of Plaxis system on stability and stress-deformation state of reverse slopes to define correlation with distances between the source of vibration and position of the slope. This problem was solved as an axially symmetric task. Reverse slopes are stable according to the model using dynamic load (coefficient of stability F=1.4). Parametric study enables us to evaluate influence of dynamic load depending on distances between the base of slope and the point of blast. In this case we documented that discussed distances do not have principal influence on the degree of slope stability but takes more significant effect on deformation situation in the slope. Dependence of values of horizontal displacements in a point located 50 meters far from the hill (railway is situated here) on distance of vibration source and the base of slope will be demonstrated. This analysis is performed both with and without material absorption. Differences between finite values of horizontal displacements in these two models are minimal.

### AN EXPERIMENTAL STUDY OF THE LIQUEFACTION RESISTANCE OF SAND-CLAY MIXTURES – ID 351

*M. Ghahremani, University of Tehran, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*

The properties of clean sands pertaining to liquefaction resistance have been studied extensively. However, natural sands generally contain significant amount of clay and/or silt mixtures. The cyclic response of such soils is different from that of clean sands. There is much less data on soil mixtures than pure soils and the available data often provide inconsistent evidence on the behavior of soil i.e. effect of non-plastic fines on liquefaction potential of sands. The problem becomes more complicated when dealing with sand-clay mixtures because of the cohesion between sand and clay particles. This paper investigates the effects of plastic fines on the behavior of Firouzkooh sand (No.161) using liquefaction resistance as a comparative parameter. Two sets of triaxial cyclic tests were conducted using different plastic fine contents and different plasticities. The plastic fines were kaolin and bentonite. The first set of tests was performed by adding 0, 10, 20, 30, 40, and 50% of kaolin to sand at a mean effective confining stress. In order to be able to compare the results, reconstituted samples with different kaolin contents were tested at the same void ratio. It was found that by increasing the fines up to 30%, the liquefaction potential increased; whereas, with the addition of more fines it decreased. Also the effect of plastic fines on the excess pore pressure ratio (ru) and deformability of the mixture was studied. In the second set of tests the plasticity of fines were changed by combing different proportions of kaolin and bentonite. It was found that as the plasticity of the fines increased, the liquefaction potential decreased. Finally, a study involving the scanning electron microscope (SEM) was also carried out in conjunction with the test program to assist in the development of a rational framework to explain the observed behavior of mixtures.

### NUMERICAL SIMULATION OF EARTHQUAKE-INDUCED PHENOMENA IN SAND – ID 376

*S. A. Savidis, Technical University of Berlin, Germany*
*D. Aubram, Technical University of Berlin, Germany*
*F. Rackwitz, Technical University of Berlin, Germany*
*W. Schepers, Technical University of Berlin, Germany*

It is well known that the ground motions on soil deposits under seismic loading depend on local soil conditions, and often are larger than those of the rock outcrop. Especially granular soils may underlie a complete loss of shear resistance resulting in large permanent deformations and lateral spreading of earth structures. However, this liquefaction phenomenon under undrained conditions only occurs if the sand is sufficient loose. The same sand in a dense state would evoke cyclic mobility and limited deformation.

In the last decades great effort has been made to predict the soil response beforehand of an earthquake to minimise conditions to which buildings or infrastructure are subjected. A large amount of constitutive equations for soil makes the choice for the user almost unmanageable, but only a few of recent contributions simulate the mechanical behaviour of sand over a wide range of densities and stress states using a single set of parameters. The dependency of sand on the stress state, density state and drainage conditions as well as on the loading history renders the problem highly non-linear and, therefore, can only be solved numerically. It turns out that the

choice of the computational tool is as important as the mathematical modelling of the material.

The paper gives a brief overview of the capabilities of geotechnical earthquake engineering by coupling an advanced constitutive equation for sand with a powerful finite element computer code. After summarising requirements of the numerical implementation, the simulation of the earthquake induced shear wave propagation in sandy soil layers is presented. The results show that an incorporation of the void ratio as a state variable consistent with on-site conditions enables realistic simulations of excessive pore pressure development. In respect thereof, liquefaction merely appears as a special case for loose sand.

### ARE RAKED PILES BAD FOR SEISMIC LOADS? – ID 377

*A. Giannakou, National Technical University of Athens, Greece*
*N. Gerolymos, National Technical University of Athens, Greece*
*G. Gazetas, National Technical University of Athens, Greece*

Raked piles find frequent use in foundations when lateral resistance is required to transmit horizontal loads, such as those arising from earth or water pressures. For years, however, the seismic behaviour of raked piles (also called battered piles) has been considered detrimental, and many codes required that such piles be avoided (e.g. French Seismic Code AFPS 90, Eurocode EC8 / Part 5). However, in recent years evidence has been accumulating that inclined piles may, at least in certain cases and if properly designed, be beneficial rather than detrimental both for the structure they support and even for the piles themselves. In this paper 3D finite element analyses are performed in order to investigate the static and seismic response of pile group configurations including batter piles. Two typical pile groups, each consisting of two piles, are studied: (a) one comprises of a vertical pile and a pile inclined at 25 degrees, and (b) a group of two vertical piles. The latter is used as a reference for comparison with the batter pile group in order to detect the beneficial or detrimental role of pile inclination to the seismic behaviour of the foundation. The dynamic response of the fixed-head pile groups is studied in: (a) a homogeneous soil deposit, and (b) a non-homogeneous soil deposit whose shear modulus increases linearly with depth. The effects of pile-to-pile interaction on the static and dynamic response of the pile groups are investigated and their response is compared to that of the single pile. Only inertial type loading is considered in this paper since group effects are more profound for this type of loading. The influence of the most important parameters of the problem is analyzed and non-dimensional diagrams are derived of the role of raked piles on pile group response.

### RATE EFFECTS ON DEFORMATION CHARACTERISTICS OF SOFT ROCKS UNDER LARGE CYCLIC LOADING – ID 394

*D. J. Peckley, University of Tokyo, Japan*
*T. Uchimura, University of Tokyo, Japan*

The minimal settlements of the foundations of the longest suspension bridge in the world after the 1995 Kobe Earthquake have demonstrated that soft rocks are competent foundation materials for large-scale structures. In order to design more cost-effective, large-scale foundations on soft rock, however, more studies should be conducted on the deformation characteristics of soft rocks under large cyclic loading. This paper presents the results of cyclic tri-axial loading tests on natural and artificial soft rocks under large loading amplitudes. The main objective of the tests is to evaluate the effects of loading rate on the deformation characteristics of these materials, as their behavior under monotonic loading was found to be rate dependent. Both longitudinal and lateral deformations have been measured in the tests using Local Deformation Transducers (LDTs). The test results show that the slow loading rates currently employed in tri-axial testing of soft rocks can cause significantly overestimated residual deformations. These results also show that loading rate can have considerable effects on stiffness and damping ratio during large cyclic loading.

### DYNAMIC BEHAVIOUR OF TAILING DAM UNDER THE ROCKBURST INDUCED GROUND MOTION – ID 496

*T. Tatara, Cracow University of Technology, Poland*
*P. Kubon, Cracow University of Technology, Poland*

Collection of floatation tailings demands in many cases building of special dams. These geotechnical structures are often subjected to dynamic loads such as the rocbursts inducing ground motion. In dynamic calculation of these structures we need to know their dynamic characteristics. This goal is realized in two ways by means of: a) analysis of numerical models and b) dynamic investigation of real structure. The problem of obtaining the dynamic characteristics of the tailing dams is indifferently distinguished.

The study presents dynamic investigation in situ of one of the tailing dams in Poland. First part of study is focused on establishing resonant frequencies of the structure in three directions. Analyses have been performed in frequency domain using recorded vibrations in chosen cross-sections of structure. Analysis of power spectral density (PSD) and transfer function (TF) plots permit to establish resonant bands of structure. As the input and output signals the records at the basement and at the points in cross-sections are respectively chosen.

In the paper, selection of dynamic model of chosen tailing dam has been also presented. The model has been assumed as elastic shield in plain strain. Three variants of dynamic model have been considered. In particular variants of model there have been applied: 1) the material data of the layers constituting the structure are calculated on the basis of shear wave velocity. The body waves velocities measurements were executed up to 30 m depth by down hole and cross hole methods, 2) effective stresses in soil resulting from weights of water and soil, 3) saturation ratio. The comparison of measurement results with calculated ones permits properly to establish dynamic parameters of the model. The proposed and validated model can be applied in further dynamic calculations. Calculations have been performed using Abaqus V 6.4 and Z_Soil codes.

### CENTRIFUGE MODEL TEST ON SEISMIC STABILITY OF A QUAY WALL IMPROVED BY CHEMICAL GROUTING – ID 505

*K. Daitoh, Musashi institute of technology, Japan*
*N. Suemasa, Musashi institute of technology, Japan*
*S. Simada, Kyokado engineering, Japan*
*T. Sasaki, Kyokado engineering, Japan*

Large earthquakes often attacked cities in Japan and caused severe damages to infrastructures. Liquefaction was one of the common causes of such damages. Though the sand compaction pile method is one of the most useful countermeasures for the liquefaction, it is difficult to apply it to existing structures. The chemical grouting method has been focused as a liquefaction countermeasure for existing structures since some grouting materials of high durability were developed. In this study, cyclic triaxial tests and uniaxial compression tests have been conducted to examine the characteristics and the durability of specimens improved by a grouting material of high durability. A series of centrifuge model tests using a tilting container and stability analyses were performed on a sheet pile quay wall improved by the chemical grouting to investigate the efficiency of the chemical grouting method. The testing system with the tilting container used directly corresponds to the horizontal seismic coefficient method as a seismic design method. As a result, it was found that the failure patterns observed were classified by block failure, 2wedge, tilting and sliding. The results of the analyses corresponding to the failure patterns were in good agreement with the test results.

### LABORATORY INVESTIGATION FOR ESTIMATION OF SEISMIC RESPONSE OF THE GROUND – ID 519

*C. Arion, UTCB/CNRRS, Romania*

*C. Neagu, National Center for Seismic Risk Reduction, Romania*

Laboratory measurements of soil properties can be used to supplement or confirm the results of field measurements. They can also be necessary to establish values of damping and modulus at strains larger than those that can be attained in the field or to measure the properties of materials that do not now exist in the field, such as soils to be compacted. The Dynamic Deformation Characteristics of the soil are used in order to calculate seismic response of ground, earth structures and structure-ground response. The improved cyclic triaxial equipment installed at CNRRS is used, when the dynamic proprieties of the soil must be obtained. In this test a cyclic load is applied to a column of soil over a number of cycles slowly enough that inertial effects do not occur. They are also used to express phenomenons that make soil to fail under seismic loading.

## GEOTECHNICAL IN SITU INVESTIGATION USED FOR SEISMIC DESIGN OF BUILDINGS – ID 521

*C. Arion, UTCB/CNRRS, Romania*
*E. Calarasu, INCERC/CNRRS, Romania*

The present process of harmonization of Romanian seismic codes with European standards requires that the effect of local site conditions be included through the soil factor, S, which must be included in the National Annex of Eurocode 8. The results of the SPT, downhole prospecting and CPT tests from the only one available Romanian site (Bucharest Tei) will be presented. The borehole data and the experimental research performed in the last years revealed a new series of elements regarding the stratification and soil characteristics in Bucharest. The evaluation of the soils liquefaction resistance based on in situ tests and the use of the earthquake records from the vertical array will be presented.

## MECHANISM AND REASONS OF SLIDE IN TABRIZ NORTH HIGHWAY (TABRIZ, IRAN) – ID 591

*E. Ghanbari, Azad University of Tabriz, Iran (Islamic Republic Of)*
*R. Vafaei, Azad University of Tabriz, Iran (Islamic Republic Of)*

Most observed or inferred landslides (falls, slides, flows) generally affect a very limited area; therefore their management requires a well-defined analysis and local only in terms of prevention or remediation. Using of landslide and the trend of stabilization measurements is important in recognition and analysis of landslide for recognition of landslide for recognition of landslide mechanism, geotechnical and geometrical information, slide and vibration conditions and recognition of unstable factors are main factors in slip analysis. Most of landslides in normal condition are stable. But encounter with impeller factors such as construction, earthquake. Freeway construction in toe and other diverse factors, they become unstable. A scientific reason which proves that if a slope before applying impeller factors will be stable and after that will be unstable is important since in case of precise recognition can gain important information about stabilization. Slope stabilization analysis in this paper has done.

Keywords: Landslide, Remediation, Slope stabilization, Geotechnical, Geometrical, STABL software.

## EVALUATION OF NEAR-FAULT GROUND MOTION INTENSITY MEASURES EMPLOYING NEURAL NETWORK ANALYSIS – ID 660

*P. Georgarakos, NTUA, Greece*
*R. Kourkoulis, NTUA, Greece*
*N. Gerolymos, NTUA, Greece*
*G. Gazetas, NTUA, Greece*

This study evaluates the validity of different ground motion intensity parameters as estimators of earthquake destructiveness, by investigating the predictive capability of: (i) peak ground acceleration, A , (ii) peak ground velocity, V, (iii) maximum velocity step, DV, (iv) Arias Intensity, IA, and (v) average spectral acceleration between T=0.2 and 0.6 sec, SA,av . We consider as a simplified damage intensity measure the maximum displacement of a rigid block supported through Coulomb friction, on: (a) horizontal base — symmetric sliding, (b) sloping base — non-symmetric sliding. We investigate the correlation between this simplified damage intensity measure, with the above mentioned earthquake intensity parameters. Symmetric sliding is a representative damage indicator for elastoplastic systems (e.g. buildings and bridges). Non-symmetric sliding is representative of systems such as retaining walls, slopes, and embankments. As excitation we use: (a) wavelets with near-fault characteristics, (b) 70 near-fault accelerogramms bearing forward-rupture directivity and fling step effects. The following parameters are examined: • safety factor tan(phi)*g/A for the symmetric, and ay/A for the non-symmetric case, where ay is the yield acceleration, • dominant frequency of the ground motion, • the form and the details of ground excitation (number of cycles and details of wavelet incorporating "directivity" and "fling" effects), • slope orientation with respect to ground motion direction (non-symmetric case). No clear correlation is indicated between "damage" (maximum sliding displacements) and any of the examined earthquake intensity measures individually. The sensitivity of the "destructiveness" to the above parameters is investigated applying neural network (NN) analysis. Our NN analysis reveals a non-linear combination of some of the above intensity parameters to be an "optimum" destructiveness measure. Factors that have a control on sliding but can not be encompassed in the above measures include the detailed sequence and size of long-duration pulses, and orientation of excitation in non-symmetric structures.

## NUMERICAL ANALYSIS OF FULL-SCALE LATERAL-LOAD TESTS OF A 3X5 PILE GROUP – ID 700

*T. Tobita, Kyoto Univeristy, Japan*
*S. Iai, Kyoto University, Japan*
*K. Rollins, Brigham Young University, United States*

2D finite element analysis based on the multi-shear mechanism constitutive relationship, FLIP (Iai et al. 1992), was employed to simulate the full-scale lateral-load tests of pile group conducted at the site in the Salt Lake City International Airport. The present analysis was conducted under drained condition with step by step loading at the pile head. To mimic the three dimensional effects associated with the pile behavior in the soil, soil-pile interaction springs were attached between soil and pile nodes. Values of these spring coefficients were determined internally based on the separately derived empirical relationship. These values were derived by the assumption that confining stress to piles is high enough so that soils surrounding piles virtually have no vertical movement, namely, soil-pile interaction is considered in two dimensional or in the horizontal plane. It is true if confining stress is high, i.e., nodes are located deep or pile movement is small. However, at the shallow depth, soils suffer less confining stress and pile movement is large, and a soil wedge in front of piles moves vertically, therefore, three dimensional effects must be introduced. In FLIP, because aforementioned assumption tends to give large soil-pile interaction spring coefficient at shallower depth, a coefficient called "PFACT" is multiplied to the spring coefficient to reduce the spring force. In the present analysis, PFACT=0.6 was used to the spring coefficients shallower than 3.06m and PFACT=1.0 was used to the rests. Model parameters for the ground and pile are obtained from laboratory tests results. After calibrating model parameters for a load-deflection curve, load-maximum moment curve and moment-depth curve of single pile test results, group pile results are compared in terms of load-deflection curve and moment-depth curve. Numerical analysis gives fairly consistent results with the one obtained from the full-scale tests.

## SEISMIC RESPONSE OF WRAP-FACED REINFORCED RETAINING WALLS – ID 749

*A. Murali Krishna, Indian Institute of Science, India*
*G. Madhavi Latha, Indian Institute of Science, India*

Recent earthquake experiences, all over the world, evidenced the effective performance of retaining walls constructed using reinforced soil during earthquakes, in the absence of foundation liquefaction, lateral spreading or sliding. Studying the performance of reinforced retaining walls under cyclic ground shaking conditions helps to understand better how these walls actually behave during earthquakes and to establish precise design procedures. This paper studies some of the important behavioral aspects of reinforced soil retaining walls under dynamic conditions through shaking table tests. Observations from experiments on models of geotextile reinforced soil retaining walls subjected to horizontal base shaking are presented. A computer controlled hydraulically driven single degree of freedom shake table is used in these tests. Models of retaining walls have been constructed in a laminar box with geotextile reinforcement using the wrap around technique with dry sand backfill. The test walls are constructed to a size of 800×500 mm in plan and 600 mm deep. The model retaining wall is constructed in lifts, each lift is reinforced with a layer of geotextile and wrapped at the facing for a length of 10 cm. The tensile strength and pull out capacity of the geotextile are measured as per the ASTM standards. The model is instrumented with ultra sonic displacement sensors, accelerometers and soil pressure sensors at different locations. Horizontal displacement of the facing and the settlement of the crest, acceleration response and pressures at different levels are measured during shaking. The models are tested under different surcharge loadings over the finished surface of the retaining wall. The response of the reinforced retaining walls with the variation in the frequency and amplitude of shaking, spacing and length of geotextile layers has been monitored and discussed in detail in this paper.

## SEISMIC STABILITY OF TOWER CRANE WITH PILE FOUNDATION IN LOAM GROUND – ID 768

*F. Arai, Musashi Institute of Technology, Japan*
*T. Katada, Musashi Institute of Technology, Japan*
*N. Suemasa, Musashi Institute of Technology, Japan*
*K. Itoh, National Institute of Industrial Safety, Japan*
*S. Tamate, National Institute of Industrial Safety, Japan*
*Y. Toyosawa, National Institute of Industrial Safety, Japan*

The Japanese design code of the crane provides that the seismic load is 20% of dead load. The tower cranes supported by the pile foundation are used when constructing the high-rise building. The earthquake resistance of the temporary structure is inferior to that of the permanent structure. The long and slender structure such as the tower crane may be vibrated largely by strong motion. In addition, the dynamic characteristics of the structure with pile foundation are greatly affected by the surrounding ground and the foundation type. Therefore, this code does not correspond to the dynamic stability. This research tries to analyze experimentally the dynamic soil-pile-structure interaction of the tower crane. The vibration characteristics of the tower crane on loam ground (called Kanto-loam in Japan) are analyzed by the centrifuge shaking table tests. In this experiment, two load conditions were adopted by using Hammer head type model. As the results, the responses of the acceleration, displacement and bending moment are increased in case of strong earthquake. The dynamic stability of tower crane decreased. Therefore, it is necessary to reexamine or establish about the pile foundation and the seismic load in the design code of the tower crane with pile foundation.

## SEISMIC HAZARD ASSESSMENT OF BANDAR ABBAS DRY DOCKS, IRAN – ID 788

*K. Rokneddin, Soil Mechanics and Technical Lab. Co., Iran (Islamic Republic Of)*
*M. Karimpour Fard, Soil Mechanics and Technical Lab. Co., Iran (Islamic Republic Of)*
*Y. Jafarian-Marzouni, Iran University of Science and Technology, Iran (Islamic Republic Of)*

Two 300,000 ton dry docks -the largest in the middle east- are being constructed on southern port of Bandar Abbas, Iran. This is a strategic harbour on the Persian Gulf banks with high risk of earthquake. In this study, both probabilistic and deterministic approaches have been utilized for seismic risk assessment of the construction site to compensate for lack of extensive risk survey on the region. To consider the site amplification effect, an equivalent linear analysis has been run on the subsurface soil layers. The resulting Annual Probability of Exceedance (APE) diagrams are suggested to be used in the similar projects in the area.

## MODELING OF SATURATED SAND UNDER DYNAMIC LOADS USING MODIFIED DISTURBED STATE CONCEPT – ID 798

*S. I. Kim, Yonsei Univ., Korea, Republic Of*
*K. B. Park, Yonsei Univ., Korea, Republic Of*
*K. B. Seo, Yonsei Univ., Korea, Republic Of*
*S. Y. Park, Yonsei Univ., Korea, Republic Of*

Over the last 30 years or so, there have been several soil models for describing undrained behaviors of fully saturated sand under cyclic loading conditions. Recently, the energy-based approach (Figueroa et al. 1994) and the disturbed state concept (DSC) (Park and Desai 2000) to evaluate the liquefaction potential have received great interests because these approaches provide more detailed information for dissipated energy degradation and cumulated deformations. While those models have been successfully verified for many geotechnical dynamic problems, the models have been used primarily for cyclic loading test results. For the liquefaction analysis, it is known that the sinusoidal type of cyclic loading does not realistically represent actual irregular earthquake motions. Therefore, effects of the actual irregular earthquake motions should also be taken into account for more detailed and advanced liquefaction analysis. In this paper, the main objective is to develop an improved method for the analysis of liquefaction potential and to verify the modified model that can simulate behavior of saturated sand under dynamic loading conditions. The model is developed through modification of the DSC model. For the evolution of the model, general formulation for the DSC constitutive model is modified and calibrated for more realistic description of dynamic responses of saturated sand using the energy dissipation approach. Especially, the disturbance caused by an applied force in the DSC model is defined by cumulative stress using damage concept. A procedure for back-calculation is developed based on the incremental integration method as well. In order to verify the modified model, dynamic tests with various input motions including sinusoidal, linear increasing, and real earthquake motions are performed and compared with results obtained from the model. From the results of this research, it is demonstrated that the modified model provides highly satisfactory correlation with the observed laboratory behavior of saturated sand.

## MITIGATION STRATEGIES OF A GRAVITY QUAY WALL BY SHAKING TABLE MODEL TESTS – ID 816

*M. Jahangir Alam, Bangladesh University of Engg and Technology, Bangladesh*
*I. Towhata, University of Tokyo, Japan*
*T. Honda, University of Tokyo, Japan*

Damage of caisson quay wall during previous earthquakes drew attention to earthquake geotechnical engineers especially in Japan. Many model test studies, using 1-g shaking table and dynamic centrifuge, have been carried out by many researchers worldwide. Experimental study on mitigation of such structures has been done by the authors. Several series of 1-g shaking table tests were performed to shed light on possible mitigation techniques against future earthquake damages. Earth pressure on back face of quay wall, acceleration and excess pore pressures at different locations of the model and displacement of caisson wall were measured. All these measurements made it possible to study the soil-structure interaction behind quay wall during dynamic loading. Various mitigation models were tested. Mitigation models were sheet piling or SCP into foundation in seaside of wall, Grouting into foundation, soil improvement in backfill etc. Pore water pressure ratio in rubble filter was less than 0.3 in all the tests, while in

foundation sand it could reach as far as 0.7. However this was enough to soften the foundation soil and incurred excessive shear deformation which finally caused wall displacement in seaward. The wall displacement, pore pressure ratio in backfill and inertia force of wall had effect on dynamic earth pressure on wall. Pore pressure and inertia of wall directly contribute to increase dynamic earth pressure, while seaward displacement contributes to reduce earth pressure. This is the reason why authors have a strong opinion that mitigation works in seaside of wall should be such that it will allow some displacement of wall while it should not be so flexible that it would cause excessive shear deformation of foundation soil. Mitigation works in backfill could help only mitigating backfill distortions. Without improving foundation sand or preventing shear deformation of foundation, mitigation of wall displacement seems to be impossible.

### EVALUATION OF SEISMIC STABILITY OF REINFORCED SOIL SLOPES AND WALLS USING HORIZONTAL SLICE METHOD – ID 832

*H. Nouri, University of Tehran, Iran (Islamic Republic Of)*
*A. Fakher, University of Tehran, Iran (Islamic Republic Of)*

Construction of reinforced soil structures, which is considered as a new technology has developed rapidly in the last twenty years in seismically active areas. In spite of perfect performance of such structures during destructive earthquakes, the precise behavior of these structures under seismic loads is not well defined and fully known. The most frequently used method of analysis of reinforced soil structures is limit equilibrium, which has been proved to be reliable in comparison with more comprehensive methods. In the current study the seismic stability of slopes reinforced with geosynthetics has been analyzed within the framework of pseudo-static approach and limit equilibrium. The rupture surface has been modeled using a generalized log spiral and in order to avoid the conventional assumption of rigid-plastic sliding wedge, the sliding block was divided into a number of horizontal slices, which do not intersect the reinforcements, accordingly the reinforcement have no direct influence on the inter-slice forces. Following this process, the force and moment equilibrium equations for each slice or of the whole sliding wedge can be satisfied. Based on the number and nature of the equations and assumptions made, two (simple and comprehensive) formulations have been derived to determine the mobilized forces in the reinforcements. The fundamental parameter determined from the relevant formulation is the required total force in the reinforcements to maintain the stability of the reinforced structure. The equilibrium equations of internal and external forces, acting on each slice were provided to determine the most critical failure surface (length of reinforcement layers). A comparative analysis between two different formulations is made. Comparison between the results of the comprehensive formulation and published analyses shows good agreement.

### THE EFFECT OF NEAR-FIELD AND FAR-FIELD EARTHQUAKE ON THE SEISMIC STABILITY OF REINFORCED SOIL SLOPES – ID 841

*H. Nouri, University of Tehran, Iran (Islamic Republic Of)*
*A. Fakher, University of Tehran, Iran (Islamic Republic Of)*

In this paper the Horizontal Slice Method (HSM) is employed for evaluation of seismic stability of reinforced soil structures in the framework of limit equilibrium method and pseudo-static analysis. In HSM the sliding wedge is divided into a number of horizontal slices, which do not intersect the reinforcements, accordingly the reinforcements have no direct influence on the inter-slice forces. This paper evaluates the capabilities of the HSM to study the seismic stability of the reinforced soil structures subjected to far field and near field seismic loads. In the evaluation of seismic stability of reinforced soil walls and slopes in far field earthquakes the effect of horizontal seismic acceleration is studied. Accordingly the influence of a number of design parameters [coefficient of horizontal seismic acceleration (kh)], geometrical parameters [slope inclination angle ($\beta$) and slope height (H)] and geotechnical parameters [soil density ($\gamma$) and soil internal angle of friction ($\phi$)] has been evaluated using the comprehensive formulation of the HSM. The employed comprehensive formulation is conducted by extending the methodology proposed in the earlier paper. The main results of the parametric analysis are presented in dimensionless form relating to the total force in the reinforcement layers to maintain the stability of the reinforced structure and the required length of the reinforcement layers. In the evaluation of seismic stability of reinforced soil walls and slopes in near field earthquakes the influence of combined horizontal and vertical seismic acceleration is studied. The study is undertaken for slopes subjected to seismic loads due to various horizontal seismic accelerations combined with vertical seismic accelerations in both upward (positive) and downward (negative) directions. As a result the influence of combined vertical and horizontal earthquake loads on the seismic stability of the reinforced soil structures is evaluated using the two mentioned fundamental dimensionless parameters.

### EMPIRICAL EVALUATION OF CYCLIC RESISTANCE RATIO FROM SPT AND CPT TEST RESULTS – ID 858

*A. Valsamis, National Technical University of Athens, Greece*
*G. Bouckovalas, National Technical University of Athens, Greece*

In current earthquake engineering practice, the liquefaction potential of saturated cohessionless soil sites is evaluated on the basis of in situ SPT and CPT results. The use of the former came historically first (Seed & Idriss, 1971) with the use of the later following shortly after. The use pf CPT was initially indirect, i.e. CPT measurements were first transformed to equivalent SPT blow counts which were consequently used to evaluate liquefaction resistance. It was not until recently that the direct interpretation of CPT results became popular, based on an autonomous database from CPT documented case histories. In this paper, the compatibility of SPT and (direct) CPT liquefaction resistance evaluation is explored, based on geotechnical investigations where the two types of in situ tests had been preformed in adjacent locations. In all, data from 19 SPT and 19 CPT tests were examined coming from the geotechnical investigation of 5 alluvial project sites. At first, SPT- and CPT-based liquefaction resistance values were compared for adjacent investigation sites and the same depth from the free ground surface. The comparison was made separately for sands, silty sands and sandy silts and was accompanied by significant scatter which is probably due to the intense (horizontal and in depth) variability of alluvial deposits. To reduce the scatter, the comparison was then focused on direct an indirect CPT-evaluations of liquefaction resistance, as well as on direct and indirect SPT-evaluations of liquefaction resistance. This way it became evident that direct CPT evaluations are systematically higher than the corresponding ones based on SPT results. This inconsistency may be traced back to the independently drawn basic CRR-NSPT and CRR-qCPT design curves and can be corrected if the latter is somewhat displaced towards higher qCPT values. This new field evidence comes in support of previously expressed recommendations (Idriss & Boulanger, 2004).

### DEVELOPMENT OF VIBRATION PENETRATION TEST (VPT) AND RESULTS OF LABORATORY AND FIELD EXPERIMENTS – ID 896

*J. Motoharu, AIST, Japan*
*T. Selcuk, Pamukkale University, Turkey*
*N. Yoshito, AIST, Japan*

The estimation of liquefiable soils and potential mapping of liquefaction are very important for city planners, building owners, and engineers to see liquefaction prone areas and hazard levels. We propose a new method, vibration probe penetration test (VPT), which utilizes a vibration probe, acceleration meter, pore-pressure meter and electrical resistivity measurement, to determine the liquefiable soils. The VPT is different from other tests commonly used in liquefaction prediction such as standard penetration test and cone penetration test. This method uses directly dynamic response of soils for liquefaction. We did laboratory experiments using

small VPT and vessel. From the laboratory test, we confirmed remarkably electrical resistivity change and the pore-pressure increases during induced vibration. The pore-pressure increases up to the overburden pressure and it indicates the sand is liquefied during vibration. The acceleration meter attached to the surface of the probe shows significant change during vibration and it may show the response of the change of stiffness and solidness of sand around the probe. To confirm the effectiveness of this method and to verify the results, we made real size VPT probes and did penetration tests in the field. Next to the VPT tests, we also performed cone penetration tests (CPT) and standard penetration tests (SPT) and got some soil samples at certain depths with the purpose of characterizing soil conditions and comparing with VPT results. The field experiments using the VPT probe produced encouraging results. Using the acceleration and electrical resistivity change in the soil, the VPT detected response of different type of soils. The results showed that VPT may have some additional merit in some kind of soils such as sands with high contents of silts. VPT can also be used to evaluate ground improvement against liquefaction by comparing the test results measured before and after the treatment.

### A STUDY ON COMPUTATION OF SEISMIC PERMANENT DISPLACEMENT OF EMBANKMENTS CONSIDERING HORIZONTAL AND VERTICAL SEISMIC MOTION – ID 904

*Y. Hata, Nippon Koei Co., Ltd., Japan*
*N. Yamashita, Kobe City College of Technology, Japan*
*S. Kano, Hiroshima University, Japan*
*T. Tsuchida, Hiroshima University, Japan*

Since the UD component of the Hyogoken-nanbu (1995) and Niigataken-chuetsu (2004) earthquakes in Japan was very powerful, it could be important in estimating the influence of structural damage on the investigated system by vertical seismic motion. However, the effects aren't taken sufficiently into account in the seismic design of embankments. So, in this study, the modified Newmark method that response characteristics in the horizontal and vertical direction of embankment were taken into consideration at the same time is proposed. Then, the examination was done about the influence which vertical seismic response of embankment gave to the permanent seismic displacement.

### NON-LINEAR ANALYSIS OF LATERALLY LOADED SINGLE PILES – ID 922

*V. Drosos, National Technical University of Athens, Greece*
*N. Gerolymos, National Technical University of Athens, Greece*
*G. Gazetas, National Technical University of Athens, Greece*

The response of pile foundations to lateral loads is an important factor for the successful performance of several critical structures. A dynamic beam on a nonlinear Winkler foundation model is presented and evaluated in this paper. The proposed numerical tool is based on the macroscopic constitutive model developed by Gerolymos and Gazetas (2004) which is capable of simulating not only the non-linear behavior of the soil, but also the inelastic structural response ("plastic hinging") of the pile. The model parameters are firstly calibrated using the well documented in literature p–y curves, and then evaluated against the results of a series of static and dynamic full-scale and centrifuge experiments. The reasonably good agreement obtained between the calculated and the recorded responses provide experimental support for the use of the proposed model in seismic soil–pile–structure interaction problems. A discussion outlines the innovations introduced by the proposed tool along with the limitations in its use, and a preliminary parametric study evaluates the sensitivity of the soil–pile–structure system response to the numerous parameters involved to the problem. Through the analyses conducted it is proven that the development of plastic hinges in the pile, which is up to now strictly forbidden by the seismic codes, is an excellent way of reducing the seismic loads on the superstructure.

### COMPARING THE STRONG MOTION DATA OF RECENT EARTHQUAKES IN TURKEY WITH WAVELET ANALYSIS – ID 937

*B. Teymur, Istanbul Technical University, Turkey*

In recent years there were earthquakes in Turkey with magnitudes 7.4, 7.2 and 6. Kocaeli and Duzce earthquakes taking place in 1999 caused the most damage of all, both structurally and economically. During these earthquakes, damage due to surface faulting and liquefaction occurred. Various wavelet analyses were used to look at and compare the accelerations induced by the recent earthquakes. This method has been applied to some of the signals obtained from the recent earthquakes in Turkey. In this paper the strong motion data acquired from this earthquake at various locations are inspected using Fourier transform and various wavelet analyses like harmonic and wavelet numbers. Using wavelets, the variation of frequency contents with time as the earthquake proceeds was observed. Harmonic wavelet analysis is a method which has been used over the past 15 years for the analysis of non-stationary signals over time-frequency domain. This analysis proves to reveal information not available by Fourier analysis.

### EFFECT OF DENSIFICATION AS A LIQUEFACTION REMEDIATION METHOD – ID 977

*B. Teymur, Istanbul Technical University, Turkey*
*O. Mavituna, Istanbul Technical University, Turkey*
*O. Bulugan, Istanbul Technical University, Turkey*

During an earthquake, loose saturated sandy or silty soils may liquefy which may cause buried pipes or tunnels to float to the ground surface, and structures to settle or tilt. During the 1999 Kocaeli and Duzce earthquakes in Turkey with magnitudes of 7.4 and 7.2 respectively caused damage due to surface faulting and liquefaction. In this paper various liquefaction remediation methods such as densification and compaction will be discussed. Taking the damages in the earthquakes mentioned above into account, with the acceleration and soil data available from various sites, analysis will be made on the effectiveness of these methods. Also the results will be discussed with the guidelines present in the Turkish earthquake resistant design code. This paper will also discuss the effect of densification of the granular soil in various experimental tests and its behaviour interpreted to a field case. The effects of different intensity earthquakes and the strains generated in the soil below a structure will be studied.

### ANALYSIS OF SOIL–STRUCTURE INTERACTION DURING EARTHQUAKE–INDUCED LANDSLIDES ON STRAIN–SOFTENING SOIL – ID 999

*R. Kourkoulis, NTUA, Greece*
*G. Gazetas, NTUA, Greece*

The effects of earthquake induced landslides on structures founded in the vicinity of the slope crests have been observed during recent earthquakes to vary depending not only on the characteristics of ground motion, but also on the nature of the foundation and structure. The impact on the latter (for a given shaking intensity) ranges from no or minor damage, to total collapse, suggesting the possibility of interaction between the sliding soil and the overlying structure. The aim of this study is to parametrically investigate the phenomenon, exploring the effect of foundation type, load, and size, on the position of the failure surface and vice versa for various levels of ground shaking. Dynamic analyses are performed utilizing a plane-strain non–linear finite element model of the soil and the structure which captures the possible separation of the foundation from the supporting soil. The model is calibrated against published data from direct shear tests so as to simulate the observed strain-softening behavior of soil during sliding. The failure surface within the soil mass is formed as a result of strain accumulation during the earthquake and under the action of gravitational forces. Soil–structure interaction is demonstrated either as modification of the position of the sliding surface due to the existence of the structure or as a modification of the dynamic response of the structure itself. The existence of the structure is observed to either

increase or decrease the computed soil displacements, depending on its foundation characteristics.

### CYCLIC DEGRADATION MODELS IN TOTAL STRESS ANALYSIS: NEW EQUATIONS – ID 1015

*N. Allotey, Univ. Western Ontario, Canada*
*H. El Naggar, Univ. Western Ontario, Canada*

With increase in computer power, nonlinear dynamic time-history analysis continues to become a more accepted method of analysis in geotechnical earthquake engineering practice. The solution procedures available are the effective and total stress approaches. The total stress approach does not account for the direct causes of soil degradation or hardening, but rather models soil degradation/hardening in a phenomenological manner. This is usually achieved by using various soil degradation/hardening models based on the number of loading cycles.

A recent study has shown that most of the total stress approach degradation/hardening models were primarily derived empirically, and are as such are not versatile enough to be used for modeling a wide range of degradation/hardening mechanisms. This paper therefore highlights the development of new versatile equations from a fatigue damage mechanics point of view that can effectively model various soil degradation/hardening phenomena.

### ROLE OF DESIGN EXAMPLES FOR SPECIFYING SEISMIC ACTIONS IN PERFORMANCE DESIGN – ID 1048

*S. Mori, Ehime University, Japan*

Global consensus on specifying seismic actions used for design is discussed by referring to the new ISO23469: Seismic actions for designing geotechnical works. Among new trends consented through the development of this International Standard, the following features are considered the most important for future design practice: (1) Seismic actions on geotechnical works include those due to ground displacements as well as the inertia force. (2) Seismic actions specified for design depends on the types and models of analyses that are classified based on a combination of static/dynamic analyses and the procedure for soil-structure interaction classified as follows: - simplified: soil-structure interaction of a global system is modeled as an action on a substructure; - detailed: soil-structure interaction of a global system. (3) Incorporation of site-specific analysis of site effects and spatial variation may improve the reliability of design. (4) The performance criteria for foundation components should be established with a full understanding of the behavior of the overall system including both the superstructure and the foundation. In order to appropriately consider the above-mentioned features in design according to the ISO23469, some comprehensive documents are needed for code writers and practitioners. Therefore, development of document containing both design examples based on ISO23469 and guidelines for checking compatibility with it is planned in a global framework. The role of design examples for specifying seismic actions in performance design is discussed and the trend of the development is introduced in this paper.

### KINEMATIC AND INERTIAL DYNAMIC PILE CENTRIFUGE TESTS ANALYSIS – ID 1086

*N. Chenaf, Laboratoire Central des Ponts et Chausées, France*
*J. L. Chazelas, Laboratoire Central des Ponts et Chausées, France*

The Laboratoire Central des Ponts et Chaussées has just purchased an earthquake simulator in order to complete the equipment of the geotechnical centrifuge in the domain of earthquake engineering. This equipment permits to continue a long term research program on the behaviour of pile foundations under dynamic loads.

The aim of this paper is a comparison of experimental results between a single pile under shocks on the pile head, and under a moderate earthquake. In the first case, the response of the pile exhibits its inertial behaviour, accentuated by the presence of a pile cap. In the second case, the response to the earthquake exhibits simultaneously the inertial and the kinematic soil-pile interaction.

Experimental devices are presented in detail in both cases. Flexible pile model (scale 1/40) has been instrumented with 20 pairs of strain gauges, witch permit the recording of the evolution of the bending moment versus time. In the framework of an analysis of the modulus of subgrade reaction, P-y loops are built by respectively a double integration and a double derivation of the bending moments. These loops represent the evolution of the displacement y of the pile and reaction P of the soil versus time.

The representativeness and reproducibility of experiments are discussed. Results of these kinematic and inertial experiments are analysed, in terms of pile cap acceleration and displacement, bending moment and P-y loops along the pile, and compared.

### EFFECTS OF INCLINED PILE ON THE DYNAMIC AND SEISMIC PERFORMANCES OF AN END-BEARING PILE GROUP – ID 1113

*S. Escoffier, LCPC, France*
*J. L. Chazelas, LCPC, France*
*N. Chenaf, LCPC, France*
*L. Thorel, LCPC, France*
*J. Garnier, LCPC, France*

Most of the codes in practice indicate that inclined piles must be avoid in seismic area. For instance the French code PS 92 states "the use of inclined deep foundation is prohibited". Even less restrictive the eurocode 8 indicates that inclined piles are not recommended. Among the main drawbacks that have been given there is the bending moment induced in the inclined pile by the soil settlement or the large alternating forces into the pile cap. Nevertheless, recent researches on historic cases have pointed out that, in certain cases, inclined piles have had a beneficial behaviour. Unfortunately there is a lake of well-documented cases and the beneficial or the detrimental effect of inclined pile on the behavior of pile group has to be clarified.

In the framework of the European Research program QUAKER, centrifuge tests have been performed on two end-bearing pile groups (2x1). In the first configuration both piles are vertical whereas in the second case one is inclined at 25° to the vertical. In both cases the piles are capped with a rigid beam which induces a fixed-end moment condition. The effect of the inclined pile is evaluated by comparing the response of both pile groups through the bending moment profile along the piles, the axial forces and the pile cap displacement.

After the description of the experimental set up the effects of inclined pile on the behavior of a pile group submitted to horizontal shocks at the pile cap are presented (inertial forces). The first results of the seismic tests perform with the earthquake simulator recently purchases by the LCPC will be presented thereafter.

### SETTLEMENT OF FOUNDATIONS DUE TO EARTHQUAKE LOADING – ID 1180

*V. Kumar, SIU, United States*
*S. Prakash, UMR, United States*

It is a matter of common observation that foundations resting on rock generally do not experience much settlement due to seismic loading. However, foundations resting on soil may undergo settlements due to compression or densification of soil due to vibrations of the foundation induced by ground shaking or due to liquefaction of soil. Because of variations in the nature of the soil and structural loads , the seismic settlements are non-uniform resulting in differential settlement of the foundations. It is important that such settlement of the foundation be accounted for in design . If the settlements are found to be unacceptable a change in foundation type or remedial measures such as ground improvement may be necessary. Further details are discussed in the paper.

### ISOLATION METHOD FOR CUT AND COVER TUNNEL USING POLYMER MATERIAL – ID 1209

*S. Kiryu, Railway Technical Research Institute, Japan*
*Y. Murono, Railway Technical Research Institute, Japan*
*M. Tateyama, Railway Technical Research Institute, Japan*

An effective reinforcement method for the side wall of a cut and cover tunnel has not been established yet. The behavior of cut and cover tunnel is strongly controlled by the deformation of the soil surrounding the tunnel. It is said that, therefore, the best way to improve the seismic performance of the tunnel is to cut the action transmitted from the ground to the tunnel. A new concept for seismic countermeasure of the cut and cover tunnel is developed. Thin walls made by a polymer material, whose stiffness are extremely small, are constructed at both sides of the tunnel. This thin wall, which is called "the isolation wall", reduce the action transmitted from the ground and make the deformation of tunnel small. In this study, the efficiency of the newly developed method is demonstrated through the analytical simulation, especially from the viewpoint of SSI (Kinematic interaction and Inertial interaction).

### THE EFFECT OF SOIL-PILE-STRUCTURE INTERACTION ON GROUPED PILES – ID 1220

*Y. S. Chung, Korea Institute of Nuclear Dasety, Korea, Republic Of*
*I. Shahrour, Ecole Polytech'Lille, France*

In this paper, the effect of the inertial interaction on the grouped piles is numerically studied. First, the analysis results of a reference case (1x3 pile group) using three-dimensional finite elements are presented. A parametric study is followed in detail to elucidate the influence of key parameters on the inertial interaction, mainly, pile spacing, loading and superstructure frequencies, mass of the structure, number of piles, configuration of groups and finally the presence of a two-layered soil. It is shown that the numeric simulations present a positive effect of the grouped piles introduced by the reduction of the stresses in the piles with the diminution of pile spacing. The group effect is demonstrated up to the high spacing (S/D=7). It is also shown that the stresses induced in the piles depend sensitively on their positions in the group; they increase shifting from the center pile towards the corner pile.

### NONLINEAR SOIL-STRUCTURE INTERACTION ANALYSIS OF BRIDGE SUBSTRUCTURE USING CONSISTENT INFINITESIMAL FINITE ELEMENT CELL METHODS – ID 1251

*P. K. Emani, IIT Roorkee, India*
*B. K. Maheshwari, IIT Roorkee, India*

Significant research has been reported in the literature for soil-structure interaction analysis for bridges. However, most of these analyses are assuming the linear behavior of soil. It is well known that during strong ground excitations, behavior of soil is highly nonlinear. The nonlinear soil behavior affects the soil-structure interaction in a complex way especially because of the inadequacy in modeling the unbounded soil medium. In the present work, a novel method developed (by Wolf and Song) in the recent past for the modeling of the unbounded medium is used along with the better-understood and realistic nonlinear soil models (e.g. Ramberg-Osgood, Drucker-Prager). The hybrid frequency-time domain method of iterative solution is adopted in conjunction with the Consistent infinitesimal Finite element Cell Method to model both the material non-linearity and the unbounded soil medium. The effect of the soil-pile interaction is studied on a bridge pier modeled as a SDOF system resting on the soil stratum. The system is modeled to rest on a mat foundation supported on piles. The energy dissipation mechanism in the near field arises exclusively from the nonlinearities included in the plastic cyclic models. The present study also includes a comparative study of the various nonlinear soil models in modeling the site conditions. Each of the aspects considered in this study are independently validated using the available benchmark examples. The overall analysis is evaluated based on the inelastic response spectrum obtained for the SDOF system for a specified ground motion time history. Results obtained from the present method will be compared with those obtained using simple models such as using soil springs and thus significance of this rigorous approach will be evaluated. Proposed method provides a rational approach for nonlinear soil-structure-interaction analysis for bridges supported on pile foundation.

### SETTLEMENT OF DRY SAND IN ONE-DIMENSIONAL SHAKING TABLE TESTS – ID 1332

*F. Jafarzadeh, Sharif University of technology, Iran (Islamic Republic Of)*
*E. Abazari Torghabeh, University of Calgary, Canada*
*H. Farahi Jahromi, Sharif University of Technology, Iran (Islamic Republic Of)*

The tendency of sands to densify has been vastly reported. Evaluation of the possible occurrence and effects of settlement caused by earthquakes has been widely appreciated in nearly all seismically active areas. Earthquake induced settlement causes distress to structures on shallow foundations, damage to utilities that serve pile supported structures, and damage to life lines that are commonly buried at shallow depths. Loose dry sands densify very quickly. Settlement of a dry sand deposit is usually complete by the end of earthquake. This research has been conducted mainly to discuss the relationship between the settlements of sands having various densities, with different parameters. For this purpose, the results of one-dimensional shaking table tests in 1g gravitational field have been used. Eight models of Babolsar loose dry sand were subjected to different harmonic and irregular dynamic loadings. The container of the models is a laminar shear box, consisting of 24 horizontal layers. The whole size of the box is 1 m by 1 m having the depth of 1 m and the maximum strain which can be produced this way is 10% at the top of the model. The relation of settlement with various parameters such as acceleration, density of the models and number of cycles in case of harmonic loadings has been addressed.

### EFFECT OF CONFINING PRESSURE ON DYNAMIC PROPERTIES OF BABOLSAR SAND USING CYCLIC TRIAXIAL TESTS – ID 1345

*J. Sanam, SHARIF UNIVERSITY OF TECHNOLOGY, Iran (Islamic Republic Of)*
*J. Fardin, SHARIF UNIVERSITY OF TECHNOLOGY, Iran (Islamic Republic Of)*

In this study the effect of confining pressure on the shear modulus and material damping of Babolsar Sand were studied. This sand is classified as poorly graded sand, SP, according to the Unified Soil Classification System. In this research Cyclic Triaxial Tests were performed on uniform saturated sand and the specimen was a solid cylinder with a diameter of 50 mm and height of 100 mm. The apparatus used in this study, is the WFI (Wykeham Farrance International) Cyclic Triaxial Device. The specimens were compacted into the mold with wet-tamping method for desired density. A series of cyclic strain-controlled tests were conducted on two different relative densities of Babolsar Sand. The constant cyclic double amplitude axial strain during all tests was 0.5%. Frequency and effective isotropic confining pressure varied from test to test and the values of shear modulus and damping ratio were calculated for several numbers of loading cycles for each test. The variables in this study are effective isotropic confining pressure (80, 150 and 250 kPa); relative density (30% and 50%) and excitation frequency (0.5, 1 and 2 Hz). In this study, densities between 29% and 35% were considered as 30% and as well densities which range from 47% to 52% were taken as 50%. Shear modulus and damping ratio for each test were calculated for different numbers of loading cycles. The shear modulus and damping ratio for all tests were calculated from hysteresis loop. An average value of secant shear modulus and damping ratio based on the two halves of the loop were computed and known as G(mean) and D(mean). Results indicate that as confining pressure increases, shear modulus increases while damping ratio decreases.

### EXPERIMENTAL STUDY ON COUNTERMEASURE AGAINST LIQUEFACTION-INDUCED UPLIFT OF MANHOLE USING RECYCLED MATERIALS PACKED INTO SANDBAGS – ID 1363

*M. Yoshida, Fukui National College of Technology, Japan*
*M. Tonoo, Fukui National College of Technology, Japan*
*M. Miyajima, Kanazawa University, Japan*
*M. Kitaura, Kanazawa University, Japan*

About 90% of waste tyres are recycling in Japan. However, stocks of unknown use are increasing every year because the amount of waste is well over one hundred million. On the other hand, recycling of used concrete produced by reconstruction of structures is almost 100%, but an excessive supply of used concrete will be occurred several years later because of the increasing the reconstruction of structures. If the growing stocks of waste tire and used concrete will increase, additional recycling will be required. Lliquefaction of backfill soil caused uplift of many buried sewage manholes during the 2004 Niigata-ken Chuetsu earthquake in Japan. The objective of this study is to propose a countermeasure which mitigates the uplift of manholes. As a countermeasure against liquefaction, gravels made by crushing stones are installed to increase the permeability of loose sand layer with the effect of drainage and, thus, reduce the liquefaction potential. Two materials were used instead of the gravels in this study. One was rubber chips made by shredding the waste tyres, and the other was recycled gravels made by crushing the used concrete. These materials were packed into sandbags in order to improve the shear strength of materials. Sake table tests were conducted to investigate whether these materials could be used as the drainage. As a result, excess pore water pressure in sandy ground was decreased by permeability of improved layer which was installed the sandbags. Furthermore, it was clear that these methods were effective as the countermeasure against liquefaction-induced uplift of manholes.

### RESPONSE OF CIRCULAR TUNNELS EMBEDDED IN STRATIFIED SOIL FORMATION SUBJECTED TO EARTHQUAKE LOADING – ID 1439

*A. Zafeirakos, Greece*

The failure of Kizawa tunnel in 2004 Mid-Niigata (Japan) Earthquake emphasized the problem of the response of a tunnel crossing the interface of a stratified soil formation when subjected to earthquake loading. The problem of the lining's final response becomes more complicated if the shear stresses acting on the soil layer's interface exceed its shear strength. This will result in the relative sliding of the soil masses along their interface until the equilibrium conditions are again satisfied. The purpose of the present research was to qualitatively and quantitatively examine the combined effect of the soil's deformation due to the loading and the sliding mass' on the final response of the tunnel by numerical analyses, using data obtained after the field surveys conducted in the affected area by the JSCE reconnaissance team. Concerning the numerical part, a Finite Element parametric study of the generalized problem of the response of a circular tunnel with a diameter of 10 meters and a lining thickness of 0.5 meters crossing a two-layered medium was performed using the commercially available code ABAQUS. The bottom soil layer was considered rigid and the soil layer's interface was treated as frictional surface with finite shear resistance given by the Coulomb's law. A quasi-static horizontal gravitational force was applied to the elements of the soil mass to simulate the earthquake loading. The soil layers' interface friction angle, the shear stiffness ratio between the soil and the structure and the embedment depth of the tunnel into the rigid soil were varied. Each parameter's contribution to the final response of the lining was examined and finally, general design considerations are proposed.

### SEISMIC MICROZONATION OF LIMA AND CALLAO CITIES – ID 1468

*M. Rodriguez, Earthquake Research Center - CISMID, Peru*
*M. Castro Cuba, Earthquake Research Center - CISMID, Peru*
*A. Martínez, Earthquake Research Center - CISMID, Peru*
*Z. Aguilar, Earthquake Research Center - CISMID, Peru*
*D. Luna, Earthquake Research Center - CISMID, Peru*
*F. Lazares, Earthquake Research Center - CISMID, Peru*
*R. Piedra, Earthquake Research Center - CISMID, Peru*

Peru is a country located in South America, with Lima as its capital city and Callao as its main port. Geographically, Peru is located in the Circum-Pacific Belt, a high seismicity zone. The seismic activity in Peru is mainly of tectonic origin, produced by the interaction of the Nazca and the Continental plates.

Lima and Callao have experienced several high intensity earthquakes. The recent 1966, 1970 and 1974 earthquakes have caused damage due to high acceleration values that in some cases have reached 400 gal.

A Seismic Geotechnical Zonification Map of Lima and Callao, which are two strategic cities, one the capital city and the other the main port of Peru, respectively, is presented as the final conclusion of this research paper. The area considered in this project is of 3923.56 km2 approximately, including 42 districts.

The data and parameters for this zonification were obtained by compilation of information from previous research studies performed by others, and completed with a field program which consisted of soil exploration and environmental vibration measurements.

From the data of natural vibration periods and the interpretation of the geotechnical exploration program, a map of soil distribution of Lima and Callao and a map of soil dynamic behavior were prepared, and from the convolution of those, a map of seismic geotechnical zonification of Lima and Callao was obtained.

### EARTHQUAKE EFFECTS ON SOILS DYNAMIC PROPERTIES – ID 1469

*M. E. Rahhal, Saint Joseph University, Lebanon*
*G. Lefebvre, Sherbrooke University, Canada*

Major developments occurred in earthquake geotechnical engineering over the last decade, but adequate information on dynamic soil properties still proves to be essential for correct computations of ground response and soil structure interaction problems. Fundamental parameters, such as pore pressure, shear modulus, and damping ratio vary significantly with the amplitude of shear strain under cyclic loading. Authors carried out experimental work for years on clays and sands to appreciate soil behavior under earthquakes. The aim of the present work is to contribute to improve our understanding of the soil shear modulus degradation with cyclic strain.

This study covers particularly dynamic properties of some clays and sands in eastern Canada. Resonant column tests were conducted to simulate earthquake loading. Properties were measured at different shear strain levels. The research focused also on intermediate shear strains situated between 10-3% and 10-1%, allowing the determination of the threshold shear strain (TSS) for these soils. It is observed that cohesionless soils start to behave non-linearly at a lower level of strain than clays do. Two methods were used to model the behavior of soils as far degradation of shear modulus is concerned: best fit curve and best fit line. In both cases, curves representing normalized shear modulus were plotted against shear strain. An excellent agreement was observed between experimental results and modeled curves. An equation for TSS is derived. It is shown that the analyzed eastern Canadian clays, which are less plastic than the Mexico City clay, yield higher TSS values. Nevertheless, under a confining stress less than 100 kPa, low plasticity clays may show a relatively high TSS although still inferior to the one of Mexico City clay. As far as the sands are concerned, the effect of the confining stress is highlighted in the shear moduli degradation slope.

### OPTIMAL RADIUS OF KINEMATICALLY AFFECTED PILE – ID 1482

*M. Saitoh, Saitama Univ., Japan*

This study focuses on the bending strains at the head of

vertical, cylindrical fixed-head piles embedded in a homogeneous elastic stratum, and the effect of the pile radius on the bending strains, in soil-pile-structure systems where the kinematic interaction dominates.This study reveal the presence of an optimal radius that locally minimizes the bending strains of the piles.

## DOWNHOLE MONITORING INSTRUMENTATION FOR THE SITE LIQUEFIED DURING CHI-CHI EARTHQUAKE AT CHINGLIAO, TAINAN, TAIWAN – ID 1505

*T. Sheng-Huoo Ni, National Cheng-Kung University, Taiwan*
*Chi-Chih Ko, National Cheng-Kung University, Taiwan*

The main purpose of this paper is to present the installation of downhole liquefaction instrumentation in the soil deposit to study the soil behavior during soil liquefaction. The study selected a site, where is located at Chingliao, Tainan, Taiwan, to install the soil liquefaction instruments according to the site liquefaction happen during 921 Chi-Chi Earthquake in Taiwan in 1999. The alluvial soil in the site is considered to be very susceptible to liquefaction during next earthquake. One surface triaxial accelerometer, three depths low frequency triaxial accelerometers, and four pore water pressure transducers were installed in this site. The pore water pressure and seismic response at ground surface and within the soil deposit induced by earthquake will be monitored in full time using personal computer. The result obtained will be used to analyze the mechanism of soil liquefaction induced by earthquake and back-calculation of dynamic soil properties of this site. The main purpose of this paper is to present the soil properties of this site and the sensors installed in this site. Also, the analysis of seismic data recorded recently using system identification will be presented.

Keywords: soil dynamics, downhole arrays, instrumentation, soil liquefaction.

## THE EFFECT OF NON-PLASTIC FINES ON THE LIQUEFACTION RESISTANCE OF SANDY SOILS – ID 1516

*A. Papadopoulou, Aristotle University of Thessalonoki, Greece*
*T. Tika, Aristotle University of Thessalonoki, Greece*

Field observations from failures due to liquefaction have shown that the behaviour of clean sands is different from that of sands containing fines (%<75$\mu$m). To account for this, all modern codes suggest a procedure for the estimation of liquefaction resistance based on fines content. However, the results of laboratory investigations on the effect of fines on the liquefaction resistance of sandy soils are contradictory. For example, Ishihara (1996) and Amini & Qi (2000) among others found that the liquefaction resistance increases with increasing fines content, others like Tronsco & Verdugo (1985) and Vaid (1994) suggested that the liquefaction resistance decreases with increasing fines content, whereas others like Thevanayagam (2000) and Yang et al. (2004) found that there is an increase of liquefaction resistance with increasing fines content up to a critical fines content and a decrease thereafter with further increasing fines content. The purpose of the work presented in the paper is to highlight this apparent discrepancy. To this end undrained triaxial monotonic and cyclic tests on a clean sand and its mixtures with a non-plastic silt at 5,10 and 15 % contents were conducted at two densities and at the mean effective stresses of 50, 100 and 200 kPa. The undrained monotonic tests were performed in order to investigate the effect of fines on the Critical State of soils. The results of both the momotonic and cyclic tests are analyzed by means of the void ratio of the sand skeleton (granular void ratio) , eg, (eg = (VSILT+VVOID) / VSAND), which expresses the relative contribution of the coarse grained fraction on the mixture behavior. The preliminary results show that for a given granular void ratio and number of loading cycles the cyclic stress ratio increases with increasing fines content at the investigated mean effective stresses.

## MICROZONATION AND HAZARD VULNERABILITY FOR DISASTER MITIGATION STUDIES IN TURKEY – ID 1524

*A. Petrow, Turkey*

This paper will provide a summary of the results and the lessons learned from this project.

Shortly after the August 1999 Kocaeli earthquake, at the request of the Government of Turkey, the World Bank approved the "Marmara Earthquake Emergency Reconstruction (MEER)" project. Under the Land-use Planning and Enforcement of Construction Codes component of the MEER project, the Government of Turkey initiated the "Microzonation and Hazard Vulnerability for Disaster Mitigation Studies (MHVDMS)" project. The project attempts to introduce a unique blend of geologic, engineering, economic, social science, and planning disciplines to demonstrate the importance of disaster planning.

In the past, governments were willing to provide funds to bring communities back to pre-disaster conditions. This approach only re-exposed the elements to hazards. Because the elements continue to be damaged, governments started to look at ways to break the damage cycle. This has pushed Disaster Mitigation Plans (DMP) to the forefront.

Currently, DMPs are not part of the planning process in Turkey. While there are Building Code Regulations and Development Laws, they do not directly address hazards. As evident in recent disaster events, communities cannot rely on the government to meet all of their needs and provide immediate assistance. The communities must be prepared and ready to respond. This project will demonstrate the value of disaster planning, encourage the incorporation of mitigation practices, and increase communities' capabilities to respond to hazards.

As part of this transformation, existing and/or lack of legislation hindering a community's ability to take appropriate actions will be identified. This component is critical to ensure that the DMP are implementable.

The project team is comprised of foreign and local experts, local practitioners, and University Professors. The project products include: 1) a DMP Methodology Manual; 2) a Legislation Recommendations Report; and, 3) municipality-specific DMPs for the six (6) pilot municipalities.

## VARIATION OF CYCLIC RESISTANCE WITH THE ANGLE OF BEDDING PLANE IN SANDY SPECIMENS – ID 1530

*R. Saffarian, University of Tehran, Iran (Islamic Republic Of)*
*A. Ghalandarzadeh, University of Tehran, Iran (Islamic Republic Of)*
*M. Ghahremani, University of Tehran, Iran (Islamic Republic Of)*

Most of the experimental studies on reconstituted specimens are performed on samples with horizontal bedding planes. But generally in nature, sand deposits usually have different bedding plane angles. Such anisotropy is called as "inherent (or initial) anisotropy" which has been found to be effective on the results of laboratory tests. This paper investigates the effect of bedding plane angle on the cyclic resistance of sands. Reconstituted specimens were prepared with different bedding angles of 20, 40, 60 and 75 Degrees and a series of cyclic triaxial tests were performed. It was tried to form samples with the same void ratio. It was found that by increasing the bedding angle from 20 to 60 degrees, the cyclic resistance increased. Whereas, when the bedding angle became 75 degrees, the cyclic resistance was decreased. This implies the importance of bedding plane angle on the undrained cyclic behavior of samples.

## THREE-DIMENSIONAL NONLINEAR FINITE-DIFFERENCE ANALYSIS FOR SEISMIC SOIL–MICROPILE-STRUCTURE INTERACTION: PERFORMANCE OF VERTICAL AND INCLINED MICROPILES GROUPS – ID 1540

*H. Alsaleh, University Sciences and Technologies of Lille, France*

*I. Shahrour, University Sciences and Technologies of Lille, France*

This paper focuses on the behavior of micropiles group under seismic loading. A three-dimensional finite-difference analysis in the time domain is carried out to investigate the effects of soil nonlinearity and sliding at the micropile-soil interface on the seismic response of vertical and inclined micropiles group. Proper boundary conditions are used to simulate radiation effects of infinite half space. The influence of the micropiles inclination on their performance has been studied. The results show that the soil nonlinearity and sliding at the micropiles-soil interface affect significantly the seismic response of vertical and inclined micropiles group. The performance of battered micropiles is strongly conditioned by the grout-to-ground bond capacity.

Keywords: Soil-micropiles-structure interaction, Micropiles foundation, Vertical, Inclination, Earthquake, Plasticity, interface, Sliding, Kinematics, inertial, three-dimensional Modeling.

## DYNAMIC PROPERTIES OF SOLID WASTE – ID 1596

*G. V. Ramana, Indian Institute of Technology, India*

Assessment of landfill seismic response necessitates the availability of reliable dynamic material properties. During the past decade, geophysical surveys and computational studies have been conducted to investigate the seismic response of the Operating Industries, Inc. (OII) landfill in Southern California. In this paper, a survey and summary of available research results is presented. In addition, a set of OII input-output seismic records during six earthquakes is thoroughly analysed. Spectral analyses are conducted to shed light on the landfill dynamic response characteristics. A simple shear beam model is found to be useful in modelling the landfill resonant behaviour. System identification techniques are employed to estimate the landfill stiffness and damping properties. These properties are defined by minimising the difference between computed and recorded acceleration response spectra at the landfill top. The identified stiffness properties are found to be near the lower bound of those documented through geophysical measurements. Identified damping of about 5% (at resonance) is within the range of earlier investigations. Comparisons of the computed and recorded accelerations show: (i) effectiveness of a linear viscous shear beam model in simulating the landfill dynamic behaviour, for the recorded small to moderate levels of dynamic excitation (up to 0.26 g peak lateral acceleration), and (ii) potential of the employed system identification procedure for analysis of input-output seismic motions.

## ASEISMIC EFFECT OF GROUND IMPROVED WITH ACRYLIC EMULSION – ID 1657

*K. Komiya, Chiba Institute of Technology, Japan*
*K. Shikata, Hanshin Sokken Co., Ltd., Japan*
*N. Kodama, NIED, Kawasaki Laboratory, Japan*

If soil ground on the foundation has flexibility, the ground absorbs earthquake impact to the structure. Acrylic emulsion is the hydrophilic emulsion which is generally made use of the adhesive of paper labels et.al. It causes cohesive strength and flexibility by means of removing the absorbed water on acrylic-emulsion colloids. After desiccating adsorbed water, acrylic emulsion keeps intense its cohesive strength and flexibility even if water infiltrates into the acrylic emulsion once more. The aim of this paper is the development of the ground improvement method using this new material (acrylic emulsion) and the estimation of its aseismic effect of ground improved with acrylic emulsion under earthquake impact. Laboratory investigation was conducted to investigate the parameters that control the aseismic behaviour of improved soil in detail. The effectiveness of ground improvement to reduce the earth pressure applied to the foundation under earthquake impact was investigated by laboratory model tests. It was found that a better aseismic efficiency can be achieved in ground improved with acrylic emulsion than in ground improved by the existing ground improvement materials.

## STUDY ON DENSE ZONE IN SUBSOIL OF EMBANKMENT AS A COUNTER MEASURE AGAINST EARTHQUAKE – ID 1660

*G. P. Chandradhara, SJCE, India*
*S. K. Prasad, SJCE, India*
*K. Revanasiddappa, UBTCE, India*

Embankments are the most common earth structures used for railways, highways, canals and dams. The failure of embankments during earthquakes has been reported during the recent past. However the most classical failure of earthen embankments was observed during the Bhuj earthquake of January 26th, 2001 in India. Almost all the earthen dams in the region amounting to over 185 suffered severe damage during the earthquake. This paper focuses on three aspects of earthen embankments. Field investigation was carried out at four dam sites that suffered severe damage during the Bhuj earthquake. The investigation included field reconnaissance survey and field tests using Swedish sounding technique. The results revealed that the subsoil was weak in all the cases and weak subsoil was the major culprit for seismic failure of embankment.

Model tests were carried out using shaking table. The embankment model consisted of 200 mm high embankment, with 200 mm top width and 1 in 1.5 side slope with 300 mm thick subsoil. Pore water pressure sensors and accelerometers were used to measure the response. The emphasis of this paper is to compare the performance of benchmark embankment with those having dense zone placed inside and outside the toe of the embankment as mitigation measure. In order to avoid the lateral instability, the dense wall was confined by wrapping geo-textile all round. From the deformation pattern and from the recordings, it was inferred that the dense wall placed inside performed better. In order to understand the mechanism FEM analysis was carried out using GEOSLOPE. Analytical results also revealed that when the dense wall was placed inside the toe showed lesser displacement when compared to outside the toe of the embankment. The tested counter measures were found to reduce embankment settlement and lateral deformations.

## A POST-LIQUEFACTION VOID REDISTRIBUTION MECHANISM FOR LAYERED SOILS – ID 1681

*S. E. Munachen, Geohazard Research Centre, UK*

Many natural and man-made deposits contain stratified sands interposed between more impervious silt or clay seams. Such situations, for example, abound in marine sediments and the laminae generated by the hydraulic fill process. The presence of these layers can result in post-liquefaction void redistribution, causing localised dilation and concentrated shear deformations that can contribute to the instability of slopes or embankments. While analytical methods to predict soil response up to the triggering of liquefaction in the free field continue to be refined, there is still great uncertainty concerning the response of soil beyond initial liquefaction. This paper, which combines the results of dynamic centrifuge model tests, strain-path controlled triaxial tests, and novel one-dimensional column experiments, clarifies the mechanisms involved in the propagation of liquefaction through complex strata and the behaviour following liquefaction, in particular its effects on ground surface acceleration and the mode of lateral deformation.

Experimental data suggest that the spatial variation of permeability in stratified deposits can affect the rate of pore pressure build-up and subsequent dissipation during and after earthquake excitation. The onset of liquefaction-induced densification can result in the formation of water inter-layers trapped below overlying low-permeability strata, the presence of which can initiate excessive localised shear deformations. The reduction in shear strength caused by this void ratio increase and the subsequent decrease in effective stress at the layer interface is not taken into account by conventional sliding block analyses that estimate permanent ground displacements. The key consequence of void redistribution is that the shear strength and stress-strain response of the liquefied soil are not solely dependent on the pre-cyclic material properties and state, but rather can also reflect the response of the composite system.

### THE EFFECTS OF POST-SEISMIC SEEPAGE ON SLOPE STABILITY – ID 1682

*S. E. Munachen, Geohazard Research Centre, UK*

The tacit assumption made in the majority of liquefaction analyses is that no change in volume occurs prior to the initiation of pre-failure instability. However, evidence from geotechnical case studies and physical model tests suggest that granular soils, because of their high permeability, undergo localised dilation even during relatively brief dynamic events such as earthquakes. The potential for the development of instability under partially drained conditions is therefore of considerable practical importance, particularly when it may have consequences that are more severe than those occurring under undrained conditions.

An experimental investigation of the effects of pore-water migration on the initiation of pre-failure instability in a saturated sand is presented. The domain of stress space in which instability develops is identified under various strain-paths, and its relationship to the zone of instability observed during undrained shear is explored. Results demonstrate that water content redistribution may render a sand unstable that would otherwise stabilise at the quasi steady state during undrained deformation, implying that the presumption of undrained conditions cannot always be regarded as conservative. Thus, partially drained conditions that result in even very small dilative volumetric strains can trigger instability at constant shear stress that would not develop if conditions remained undrained without some initial increase in shear stress.

Pre-failure instability is affected not only by the initial state of the sand but also by the strain increment ratio imposed during shear. The response is controlled mainly by the difference between the imposed strain increment ratio and the maximum strain increment ratio obtained from a drained test conducted under the same initial effective stresses. The implications of these findings are discussed in relation to practical problems involving liquefaction.

### INITIATION OF LIQUEFACTION-INDUCED FLOWSLIDES – ID 1683

*S. E. Munachen, Geohazard Research Centre, UK*

An experimental investigation is undertaken to evaluate the stress conditions required to initiate liquefaction and the influence of various parameters on those stress conditions. The results demonstrate that sands that exhibit non-associated flow may become unstable inside the effective stress failure surface. If instability is defined as a condition for which the current applied shear stress cannot be sustained for perturbations in the state of stress, then contractive as well as dilative materials may be considered to be unstable in the region where the yield surface opens up in the outward direction of the hydrostatic axis. In this region, the soil can deform plastically under decreasing stresses. For undrained contractive material, the stability is self-sustaining and unconditional. However, for drained conditions the instability is dependent on the reduction in mean normal stress. This reduction can occur as a decrease in mean stress or as an increase in pore pressure caused, for example, by undrained creep.

The flow potential, defined as the shear stress increase under undrained conditions required to initiate liquefaction, is observed to increase with increasing relative density and mean normal stress, and to decrease dramatically with increasing initial shear stress level. The liquefaction of loose sands may, therefore, be triggered by very small changes in stress conditions if the sand is initially in equilibrium under high shear stresses, leading to the development of a flowslide when the unbalanced driving stresses exceed the steady state strength of the liquefied soil.

The relevance of the insitu stress conditions, the preloading history and the kinematic constraints on the collapse mode are discussed.

### ADEQUATE NEWMARK COEFFICIENTS FOR HYBRID (BEM/FEM) SOLUTION OF POROUS-MEDIA UNDER EARTHQUAKE – ID 2041

*H. Ghorbani, Tehran University, Iran (Islamic Republic Of)*
*K. Bargi, Tehran university, Iran (Islamic Republic Of)*
*B. Gatmiri, Tehran university, France*

One of the most important subjects in iterative solution of finite element in dynamic analysis is the stability of approximation method for approximation of velocity and acceleration terms. If fem method would be combined with bem, difficulty and complexity would be greatened. In this paper, it is used FEM/BEM hybrid method for solution of fully coupled equations of transient seepage and equilibrium equations in saturated soil as a porous media. Also in approximation of first and second derivation, Newmark scheme is used. It is researched a wide range of Newmark coefficient pairs and also stability of solution is studied. Trapezoidal method is a particular case of Newmark scheme. Evaluations indicate that, regardless of trapezoidal method stability, there are more adequate pair coefficients than trapezoidal method coefficients which can produce faster and more unconditional convergence than trapezoidal scheme. This proposed pair of Newmark coefficient, increases speeds of solution efficiently.

### ASSESSMENT OF GENERATED PORE PRESSURE AND LIQUEFACTION WITH FEM/BEM HYBRID ANALYSIS IN EARTHQUAKE – ID 2043

*H. Ghorbani, Tehran University, Iran (Islamic Republic Of)*
*B. Gatmiri, Tehran University, France*
*K. Bargi, Tehran University, Iran (Islamic Republic Of)*

In most of marine structures that is constructed in sand layer, there is liquefaction potential and it is reported frequently damage in different earthquake by liquefaction. Therefore there is a great effort to recognize pore pressure growth pattern in porous media under dynamic loading In this paper at the first step, it is generated water-porous media (seabed) interaction's equations and it is discretized by hybrid FEM/BEM in time domain. One of the most important problems in iterative solution of water-porous media interaction is low convergence speed in water and it is presented an efficient technique for overcoming this problem.

### UNDERSTANDING THE BEHAVIOR OF GRAVITY RETAINING WALLS UNDER EARTHQUAKE LOADING – ID 2060

*M. E. Rahhal, Universite Saint Joseph, Lebanon*

The seismic response of gravity walls with a cohesionless backfill is analyzed. Two separate cases are considered: dry backfill and saturated backfill. A rotating block method is used to calculate the rotational and sliding displacements. This method considers an analytical and iterative approach to calculate threshold accelerations for rotation and sliding, beyond which the displacement is initiated.

Different computer programs have been developed. These programs determine the mode of displacement of the considered gravity wall by comparing the values of threshold accelerations and actual seismic accelerations. A comprehensive parametric study covering the effect of the wall and soil parameters on the values of threshold accelerations for sliding and rotation is carried out. The study shows that heavy or slender walls are more likely to rotate under seismic loading. Moreover, careful consideration is to be given to the exact location point of the dynamic soil pressure along the wall as well as to the friction angle between the base of the wall and the soil. The analysis highlights the contribution of the rotational movement to the increase in the total displacement of the wall. On the other hand, in the case of a saturated backfill, pore pressure generation affects tremendously the seismic response of the gravity retaining wall. Interesting analysis is undertaken by comparing results with dry and saturated backfill. The effect of water on rotational and sliding threshold accelerations is analyzed. Finally, water proves again to be of catastrophic consequences in the case of seismic loading.

## ES 2: Dam Engineering
Level-1

### DAMS AND SEISMICITY OF TURKEY – ID 83

*H. Eyidogan, Istanbul Technical University, Turkey*

There are 555 dams in operation in Turkey. 212 out of 555 have been constructed under the title of large dams while 343 have been constructed under the title of small dams. 134 hydroelectric power plants were being operated by State Water Affairs and Private Companies. The total installed capacity and annual average generation of these hydroelectric power plants are 12,631 MW and 45,325 GWh, respectively. 70 HEPP are under construction or in investment program of country. Turkey lies within the eastern Mediterranean part of the Alpine-Himalayan orogenic system which constitutes one of the most seismically active continental regions of the world with a long and well documented history of earthquakes. 70% of dams are located in the first and second degree earthquake hazard zones where minimum effective peak accelerations expected to be equal or more than 0.4 g and 0.3 g, respectively. These values are put in force after 1997 and they are almost 0.1 g unit bigger than those that were previously (1975) valid earthquake codes. Only six large dams are equipped with strong-motion accelerographs. Despite the high seismic activity of the country, very few strong motion records were obtained from dams. Monitoring the induced seismicity is applied for a very few large dams in Turkey and only two reports/papers on the induced seismicity of dams are submitted in the international journals and meetings up to now. A long term strategy must be followed to equip seismically the irrigation and hydroelectric power plants of Turkey.

### AN EFFECTIVE ALGORITHM ON THE FINITE ELEMENT ANALYSIS OF COUPLED DAM-RESERVOIR-FOUNDATION SYSTEMS – ID 139

*M. Damodar, Indian Institute of Technology Guwahati, India*
*S. Vishal, Indian Institute of Technology Guwahati, India*
*K. L. Phani, Indian Institute of Technology Guwahati, India*

The fluid-structure-soil interaction has been the subject of intensive investigations in recent years. It is well known that the problem in question can be formulated at different levels of complexity and "completeness" of physical representatively. A robust solution procedure to fluid-structure-soil interaction problem is still a challenging one in computational mathematics. Direct numerical solution of the complex equations governing even the most simplified two dimensional models of fluid-structure-soil interaction requires that both the flow field and the domain shape be determined as the part of the solution, since neither of them is known a priori. The present paper deals with the finite element analysis of the coupled dam-reservoir-foundation systems considering fluid-structure-soil interaction. The pressure is considered as unknown variable parameter in the reservoir domain, assuming the water as inviscid, irrotational and linearly compressible. The infinite reservoir has been truncated by adopting an efficient truncation boundary condition for the finite element solution. The elastic dam and its foundation are analysed by two-dimensional plane strain formulation. The elastic dam, its foundation and the reservoir are treated as three separate systems and discretized with finite elements. The solution of the coupled dam-reservoir-foundation system is accomplished by assembling three system equations into a single one. A robust computer algorithm has been developed to determine the response of the coupled system. Studies show the accuracy and versatility of the developed numerical scheme. The developed algorithm can readily be used to determine the hydrodynamic pressure in the adjacent infinite reservoir as well as the displacement and stress field in the dam and its foundation.

Keywords: gravity dam; fluid-structure-soil interaction; radiation boundary conditions; dam-reservoir-foundation interaction; coupled system

### NONLINEAR SEISMIC ASSESSMENT OF REINFORCED CONCRETE RESERVOIR TOWERS – ID 160

*W. Daniell, University of Bristol, UK*
*C. Taylor, University of Bristol, UK*
*A. Crewe, University of Bristol, UK*
*R. Sabatino, University of Bristol, UK*

Published guidance on the seismic analysis of reinforced concrete intake/outlet towers is limited, especially for their nonlinear response, due to limited knowledge on the nonlinear characteristics of existing and new towers. Proving the integrity of existing towers is an international problem for dam owners, and an industrial need exists for a rational, cost-effective and validated method for their assessment.

The authors are currently involved in a research project, aiming to develop and validate a staged procedure for the seismic assessment of intake/outlet towers. The work includes:

•Developing a technique for calculating moment-curvature diagrams for tower sections. •Developing a computer program for the relatively simple non-linear analysis of towers. •Reviewing techniques for nonlinear finite element modelling for detailed analysis of towers. •Monotonic and cyclic push-over tests on scale-models of towers, to characterise their non-linear behaviour and acquire data to validate the theory.

The paper will describe the method for the analysis of arbitrary cross-sections of reinforced concrete towers, which has been implemented in a computer program to produce moment-curvature diagrams. Sections are subjected to combined bending and axial load. Analyses can be conducted for monotonic and cyclic loading. Various constitutive models are used for confined and unconfined concrete, and for the reinforcing steel. Failure criteria accounted for include concrete crushing, and buckling and fracture of reinforcing steel.

Theoretical moment-curvature diagrams have been produced for the four physical scale-models of towers that are to be constructed and tested as part of the research project. Test data will be compared with these to validate the theory.

### DYNAMIC ANALYSIS AND EVALUATION OF SAFETY OF SHPILJE DAM – ID 169

*I. Gjorgjiev, Institute of Earthquake Engineering an Engineering, Macedonia*
*M. Garevski, Institute of Earthquake Engineering an Engineering, Macedonia*
*S. Stamatovska, Institute of Earthquake Engineering an Engineering, Macedonia*

An investigation for evaluation of the seismic stability of existing earth-fill dams in R. Macedonia has been carried out. The methodology used for that purpose involved: re-evaluation of seismic hazard as well as 2D and 3D dynamic analysis of the dams. Seismic hazard analyses have been performed for the formulated mathematical models of seismic sources, the defined recurrence relations and the selected alternative models of ground motion. The results from the seismic hazard analyses are spectra with equal annual probability of exceedence of 0.01, 0.001, 0.0001 and 0.00001. The finite element approach with discretization of the dam models was applied by using two-dimensional isoparametric plane strain finite elements and 4-node three-dimensional tetrahedral elements. A 2D dynamic analysis was performed considering the nonlinear behavior of materials present in the dam body. Several possible scenarios for dam stability were accounted for: vertical and horizontal settlement of the dam crest, stability of the upstream and downstream slope against sliding, propagating tensile stresses in the dams and risk of crushing of the gallery concrete due to increased concrete compression. The conditional probability of failure has been obtained for each seismic level. The total probability of failure of each dam has been obtained as an integration of the conditional probabilities of failure and the seismic hazard curve for the dam site. A comparative elastic analysis of the structural response has been performed considering a characteristic time history of ground acceleration for the 2D and 3D dam model.

### THE DYNAMIC CONTACT MODEL FOR NONLINEAR SEISMIC RESPONSE OF HIGH ARCH DAMS WITH CONTRACTION JOINTS – ID 178

*L. Zhao, Hohai University, China*
*T. Li, Hohai University, China*
*Z. Niu, Hohai University, China*

A new algorism for dynamic contact problem—Mixed Finite Element Method, was proposed for nonlinear dynamic contact problems of high arch dams with contraction joints. Based on the characteristic of local nonlinearity for this problem, the system of forces acting on the contactor was divided into two parts: external forces and contact forces. The displacement of contactor was chosen as the basic variable and the nodal contact force in possible contact region was chosen as the iterate variable, so that the nonlinear iteration process was only limited in the possible contact surface. In this way, the sophisticated contact nonlinearity was shown by the variety of the contact forces. Moreover, in the case of multi-joints contact problem, the flexibility matrix is symmetric and sparse. Thus the iterative procedure became easily to be carried out and much more economical. Firstly, the mechanical model for three-dimensional dynamic contact problems with friction and initial gaps was presented, and its finite element compliance equations were obtained. And then, the iteration process was given in detail. At last, the opening and closing of the joints of a high arch dam was analyzed as an example according to the proposed method. It is founded that once the tensile stress exceeds the tensile strength during the earthquake, the joints will open and consequently the tensile stress will be released. This is because large arch tensile stresses can not be transferred across the contraction joints, hence arch tensile stresses releasing and the internal forces redistributing from the arch action to cantilever action will take place. Key words: Dynamic contact problems, high arch dams, contraction joints, mixed finite element method

### EFFECT OF FOUNDATION MASS AND SHAPE IN 3-D TIME DOMAIN DYNAMIC ANALYSIS OF CONCRETE ARCH DAMS – ID 205

*M. Moradi, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Noorzad, Power and Water University of Technology, Tehran, Iran (Islamic Republic Of)*
*M. Ghaemian, Sharif University of Technology, Iran (Islamic Republic Of)*

In common analysis of concrete dams subjected to dynamic loading, the foundation is assumed to be massless. Recent studies show that foundation material and radiation damping exert noticeable effects on dam dynamic response which is not considered in massless method. In this study, the finite element method is employed to simulate dam and its massed foundation in association with dam-reservoir interaction. A direct time domain procedure is used to find out the dynamic linear behavior of the three-dimensional reservoir-dam-foundation system. To investigate the effects of the shape and size of the foundation on the obtained results, rectangular and semispherical foundations with different radius are considered. Far-end boundary of the foundation is modeled by viscous boundary condition. In the finite element model, reservoir is assumed to be compressible and the coupled problem is solved by staggered displacement method. Amirkabir dam, which is located in Iran, is used for the purpose of investigation as case study. The results of the research indicate that seismic response of concrete arch dam is reduced by considering the effect of foundation mass with radiation damping. The shape and the size of the foundation in massless model do not affect the seismic response significantly. But, massed foundation with various shapes in model leads to different dynamic responses.

### STATIC AND SEISMIC SLOPE STABILITY ANALYSIS AND FINITE ELEMENT VALIDATION – ID 217

*D. Tan, Imperial College London, UK*
*S. Sarma, Imperial College London, UK*

In the seismic safety analysis of slopes, it is essential to find the critical slip surface, the critical acceleration and the corresponding slip mechanism. It becomes more so when seismic displacement approach is used as in the seismic resistant design of earth dams and embankments, which provide a better criterion for safety than load-based approaches.

In order to obtain the critical slip surface with an acceptable stress field within the sliding mass, a new procedure is recently developed, which is based on the limit equilibrium method of slope stability analysis within the pseudo-static analysis framework. The procedure uses stress acceptability as prerequisite to derive a system of nonlinear equations to determine the slip surface along with the corresponding critical acceleration. In this paper, further developments are addressed. Firstly, a slip fan approach is developed to make the solution of the topmost slice close to the Rankine active solution. Secondly, parabolic stress distribution along the inter-slice boundaries is assumed, which provide a better line of thrust. Finally, the method, which was originally used for seismic analysis, is explained here how to extend it to static analysis.

The procedure is extensively validated using elastic perfectly plastic Mohr-Coulomb model through Imperial College Finite Element Program. The different rigidity parameters and the different initial stress fields are assumed to check the independency of these conditions. If fully associated condition is adopted, good agreements are achieved between current procedure and finite element analysis, in terms of the critical acceleration, the critical slip surface and the stress distribution along the slip surface.

### EFFECT OF RESERVOIR GEOMETRY AND VERTICAL CONTRACTION JOINTS IN THE SEISMIC RESPONSE OF GRAVITY DAMS – ID 242

*M. Millan, Princeton University, United States*
*J. Young, Princeton University, United States*
*J. Prevost, Princeton University, United States*

Conventional seismic analysis of gravity dams assumes that the behavior of the dam-water-soil system can be represented using a 2-D model since vertical contraction joints allow dam blocks to vibrate independently from each other. This 2-D model assumes the reservoir to be infinite and of constant width, and no transversal variation of pressures is expected. However, many reservoirs have a width different from that of the dam. For these cases, recent analytical studies show that water pressures have transversal variation along the upstream face of the dam and, consequently that the blocks experience different pressures. In this paper, a simplified 3D analytical model and a numerical 3D BEM model in the frequency domain are used to investigate the influence of the reservoir width on the dam response, and the relative displacement between the blocks. The results show a significant increase in the seismic response of the dam when the reservoir geometry and the block divisions are considered.

### NONLINEAR NUMERICAL APPROACH FOR LONGITUDINAL DAMS – ID 287

*K. Salyamova, Institute of mechanics, Uzbekistan*
*R. Abirov, Institute of mechanics, Uzbekistan*

When solving stability problems of earth structures and underground structures like dams, dikes, water reservoirs, slopes, fills, head race, etc. there are arise some questions necessary for aseismic design. The analysis of qualitative features of their behaviour at external impact and quantitative estimations of their strength by normative documents (Codes) in most cases does not take into account the structure by 2D scheme as elastic and nonlinear continua. The technique of strength and sustainability analysis of ground and underground hydro technical structures taking into account of physical and mechanical parameters of soil properties and design features of Tupolang hydro electro station is offered in this issue.

### STUDY ON THE SEISMIC SAFETY OF AN INTEGRAL ARCH DAM SYSTEM – ID 290

*J. Tu, China Institute of Water Resources and Hydropower, China*
*D. Li, China Institute of Water Resources and Hydropower, China*
*H. Chen, China Institute of Water Resources and Hydropower, China*

In this paper, based on a new seismic safety concept of arch dam a corresponding analytical technique using FEM has been developed. In the numerical model, dam-reservoir-foundation interaction and nonlinear contact between contraction joints, dam-foundation interface as well as slide surfaces in abutment wedges are taken into consideration. Both dam body and critical abutment wedge are treated as an integral system and the system safety are determined by one single safety criteria, defined as the point of inflexion of the relationship curve between dam displacement and seismic overloading factor or shear strength reduction factor. The seismic safety of an arch dam with design peak ground acceleration of 0.5575g due to seismic overloading and shear strength reduction of the slide surfaces in the wedges are given respectively.

### CONTRIBUTION OF CONTACT ELEMENT IN MORE REALISTIC MODELING OF DAMS – ID 359

*V. Mircevska, Institute of Earthquake Engineering, Macedonia*

The contact zone between two material media of different elastomechanic and stiffness characteristics can be modeled by contact element placed at the contact between the faces of two adjacent finite elements. The contact element provides information on the normal stresses acting along the normal and the tangential stresses acting in two orthogonal tangential directions of the contact zone. The behaviour of the contact element is expressed through the relative motion of the two contact surfaces, i.e., motion normal to the contact surface, contact or separation, and motion in the plane of the contact itself, i.e., sliding along the two orthogonal tangential directions. The deformation characteristics at the contact zone are determined from the adopted stiffness in normal direction and the adopted stiffness in both tangential directions of the contact. Since the contact element is of a nonlinear type, its behaviour is determined by the adopted nonlinear constitutive laws that describe its behaviour in normal and both tangential directions. In design of dam structures, there exist certain structural discontinuities. They represent locations of high concentration of stresses and vulnerability particularly during strong earthquakes. From these reasons, modern approaches to mathematical modeling of dam structures by application of digital methods involve the so called contact elements with their physical characteristics of transferring of forces from one zone to another. Using the contact elements, it is possible to define the differential displacements at the contact between two material media of different stiffness characteristics. Despite this, it can be placed also at the boundaries of the finite elements, modeling more realistically degree of fixation in the support. In this way it is possible to eliminate the tensile stresses in the model that result from unrealistic modeling of the supporting conditions.

### INVESTIGATION OF SEISMIC RESPONSE OF EARTH DAMS USING A COMBINATION OF FINITE ELEMENT METHOD AND BOUNDARY ELEMENT METHOD – ID 423

*S. Amiri, Tabriz University, Iran (Islamic Republic Of)*
*M. Yousefzadh, Tabriz University, Iran (Islamic Republic Of)*
*J. Safadoust, Tabriz University, Iran (Islamic Republic Of)*

In the present study seismic response of earth dams by application of a hybrid formulation including consideration of contribution of underlying soil is investigated. A direct boundary element method based on the numerical discretization of general boundary integral equation of linear elastodynamic problems in transformed domain is employed for mathematical modeling of the soil (foundation) that is considered as a uniform viscoelastic half-space. The earth dam is modelled by a finite element method allowing for consideration of heterogeneous and isotropic material for the earth dam. By imposing the consistency of forces and displacements along the dam-foundation interface, the response of the combined system is evaluated. The effects of underlying soil properties as well as dam geometry on seismic response of this type of structures is explored. The problem is formulated in frequency domain and it is assumed that the earth dam is subjected to plane harmonic P waves, vertically polarized S waves and Rayleigh surface waves for which the displacement spectra are presented. In addition, a brief discussion on stress distribution within the dam due to seismic excitation is presented.

Keywords: Soil-structure interaction; Boundary element method; Finite element method; seismic response

### COMPARISON OF STOCHASTIC AND DETERMINISTIC ANALYSES OF KEBAN DAM TO ASYNCHRONOUS SEISMIC EXCITATION – ID 436

*M. Akkose, Karadeniz Technical University, Turkey*
*S. Adanur, Karadeniz Technical University, Turkey*
*A. Bayraktar, Technical University, Turkey*
*A. A. Dumanoglu, chnical University, Turkey*

The seismic ground motion has finite wave velocity and it arrives to support points at different times due to the complex nature of the earth crust. Therefore, the travelling wave effect of the seismic ground motion cannot be ignored when considering the dynamic response of the large structures. The effect results from the difference in the arrival times of waves at support points is named as the wave-passage effect in literature. In addition to the dynamic displacements, quasi-static displacements will take place on the structure due to the wave-passage effect. When the ground motion is considered to be traveling with finite wave velocity, the equation of motion, therefore, has to be written in terms of total displacements that have quasi-static and dynamic components.

Structural responses subjected to dynamic loads can be evaluated as deterministic and stochastic approaches. For structures excited by loads with random characteristics, the responses can be predicted more realistically if stochastic approaches are adopted. In the deterministic approach, a recorded accelerogram is used as the input motion at one point, and the differential motion between two points is obtained by a delay in the arrival of the seismic wave between the points. In the stochastic approach, however, a power spectral density function for acceleration is assigned.

Stochastic and deterministic responses of Keban Dam to asynchronous seismic excitation are compared in this study. This dam, which is located in Elazığ, Turkey is a rock-fill dam. The E-W component of the Erzincan earthquake, March 13, 1992, Erzincan, Turkey, is used as ground motion. In the stochastic and deterministic seismic analyses of the dam, 1000m/s, 2000m/s, 4000m/s and infinite velocity are used as earthquake wave velocity. Displacements and stresses on the dam are obtained for the earthquake wave velocities and compared with each other.

### CONSIDERATION OF NON-LINEAR EFFECTS IN SEISMIC RESISTANCE DESIGNS OF CONCRETE HYDRAULIC STRUCTURES – ID 502

*V. Bronshteyn, Geodynamic Research Center, Russian Federation*
*M. Groshev, Geodynamic Research Center, Russian Federation*

Assessment of stress-strain state and prediction of behavior of concrete hydraulic structures at seismic loads is used usually to be made nowadays within the frames of linear-elastic analysis. However, the level and scales of tensile stresses development to be predicted in such analysis for many concrete dams operating in the areas of high seismic risk are indicative of inevitability of opening the joints in the structures, non-linear defor-mations and cracking of concrete during maximum design earthquake. Without consideration of the non-linear effects of geometric and physical type it is impossible to develop a correct mathematical model of concrete dams' behavior during earthquakes and evaluate their actual seismic resistance. Solution of non-linear problems in dynamic formulation is complicated by: the necessity of realization of conditions of free wave transmission through a boundary; unfeasible application of

superposition principle for taking into account both static and dynamic components of the solution; incorrectness of application of response spectrum method for determination of stress-strain state of a structure and associated mass method for considera-tion of the dam-aquatic environ interaction, etc. In a general case solution of non-linear dynamic problem with consideration of its peculiar features may be obtained by application of block-contact model for the "dam-foundation" system and non-linear model of concrete behavior for contacting blocks. The mentioned approach has been realized at validation of seismic resistance of the Sayano-Shushenskaya arch-gravity dam, 242 m high. The problem was solved in 3D formulation specifying seismic load by three-component accelerogram with PGA Ah1=0.25g, Ah2=0.23g and Av=0.18g. In contrast to the linear-elastic analysis which did not allow for validation of seismic resistance of the dam under CEM impact, consis-tent with the results of non-linear dynamic analysis, the seismic resistance of the dam is ensured due to re-distribution of forces, non-linear concrete deformation, dissipation of seismic energy.

## SEISMOMETRICAL OBSERVATIONS ON HIGH DAM OF KYRGYZSTAN – ID 523

*V. Dovgan, Kyrgyz-Rassian Slavic university, Kyrgyzstan*

The highland Kyrgyzstan, located in Tien-Shan, possesses a unique hydropower complex. The basis of this complex is made with cascade of Toktogul Hydroelectric power station on the Naryn river. Most powerful of working - Toktogulskaya - has a concrete gravitational dam in height of 215 meters and a water basin in volume 19.5 billion cubic meters. The dam is at height of 900 m in a deep canyon with a high level of natural tectonic stresses. On modern and historical seismicity the Toktogul district is attributed to the zone of the possible sources of earthquakes with magnitude 7.5. Regular engineering – seismometric researches were not realized directly on the dam, only the small technical group carried out and continues to carry out natural measurements. Now the system of seismometric observations has created on the Toktogul hydroelectric power station. 27 seismometers have established in 9 points at different levels of the dam and in the boards. One point of observations is located on distance of kilometer from hydrounit and is basic. The system of data collection is submitted by two subsystems connected by a telephone line: one is on the dam, another is located in the capital of republic - Bishkek city in laboratory of the Kyrghyz -Russian Slavic University. The primary tasks of forthcoming researches: Estimation of a condition of the dam and slopes on a complex of the seismometric and natural supervisions data; Development of a control tool technique of canyon slopes stability of Toktogul hydrounit at seismic influences; Development of forecast methods of the dam conditions, its basis and coastal contiguities at seismic influences. For performance of researches is saved already up the significant material, preliminary results are received. In performance of work participate: The Kyrghyz-Russian Slavic university (Bishkek); Institute of geospheres dynamics of the Russian Academy of sciences ( Moscow).

## LIQUEFACTION IN FOUNDATION GROUND OF EMBANKMENT DAMS (CASE STUDY: AHAR DAM, AZERBAIJAN, IRAN) – ID 590

*E. Ghanbari, Azad Univerist of Tabriz, Iran (Islamic Republic Of)*
*A. Saberi, Water Corp. of East Azarbaijan and Ardabil, Iran (Islamic Republic Of)*

Liquefaction in foundation ground of an earth dam is a major concern in stability of embankment dams. The first step in evaluating the liquefaction potential of soil is determining the sheer stress induced by a given earthquake (CSR). Then cyclic resistance ratios (CRR) that can cause liquefaction in deposit are estimated and compared with CSR in various depths. This subject is investigated as a part of a seismic assessment of Ahar dam in E. Azerbaijan of Iran in two loading states. First, natural deposit conditions (without the dam) and second in considering of the dam weight and water up to normal water level (N.W.L.) of the dam on the deposit. In each of these two states, methods proposed by Seed et al. (1985) and Tatsuka et al. (1980) are used to evaluate CRR. Minimum stress obtained form these two methods are used to calculate the factor of safety. The results show that occurrence probability of liquefaction in deposit decrease after the construction of the dam in comparison with natural deposit conditions. Nevertheless, construction of dam doesn't affect significantly the deposits that not situated under the dam.

## RESPONSE OF KEDDARA DAM TO SPATIALLY VARYING EARTHQUAKE GROUND MOTION – ID 596

*S. Louadj, UMMTO, Algeria*
*R. Bahar, UMMTO, Algeria*
*N. Laouami, CGS, Algeria*

Spatial variation of earthquake ground motion is an important phenomenon that cannot be ignored in the design and safety of strategic structures. The purpose of the present study is to analyse the seismic response of the Keddara rock fill dam to varying earthquake ground motion. A space-time earthquake ground motion model that account for both coherency decay and seismic wave propagation, is used to specify the support motions. The soil parameters are integrating by modelling the coherent component with the commonly used Kanai-Tajimi power spectral density. The Keddara dam, located on the Boudouaou River in Boumerdes region about 35 km east of Algiers, was shaken strongly by the May 21, 2003 Boumerdes earthquake (Mw=6.8). With a crest length of 486m and 106m high, the Keddara dam was selected since it has been well instrumented with accelerographs during this earthquake. Accelerometers are located along the crest, at the left and right abutments and at the centre. Linear elastic and equivalent elastic analysis, using the finite difference computer program FLAC5.0 indicate that the spatially varying ground motion reduces the acceleration response at the crest. In addition, seismic calculations are performed assuming the soils, constituting the dam, as Mohr Coulomb materials. Damping is accounted for by the hysteretic damping and a small amount of viscous damping (2%) is used to limit response at very low strain levels.

## DYNAMIC ANALYSIS OF CONCRETE FACE ROCK-FILL DAMS USING NUMERICAL AND ANALYTICAL METHODS – ID 649

*Z. Ghannad, Kayson Co., Iran (Islamic Republic Of)*

Finite element method has been known as a modern method to investigate dynamic behavior of embankment dams in high seismicity regions. In spite of some advantages such as ability to consider appropriate dam geometry, dam internal zoning and different constitutive models but it's time consuming and costly method which its total accuracy directly depends on hardware/software advancement. On the other hand, there are some analytical methods developed based on simplified theories, mainly shear slice theory. This analytical method can be used easily and quickly according to simplified assumptions. In this paper results of numerical and analytical analysis for a concrete face rockfill dam is presented and compared. This is a 104m high dam, one of the two CFRDs of a pumped storage project which is located in a high seismicity region of Iran. Response of dam to input ground motion is investigated based on both finite element and analytical methods and the results have been compared. The comparison is formed based on time domain responses such as crest acceleration and natural frequency analysis. The results show that the analytical method is simple and fast and has enough accuracy for preliminary stages of dam design.

## ASSESSMENT OF PERMANENT SEISMIC DISPLACEMENTS ON AN EARTHFILL DAM: A CRITICAL OVERVIEW – ID 796

*N. Klimis, ITSAK, Greece*
*A. Anastasiadis, ITSAK, Greece*

*K. Makra, ITSAK, Greece*

The seismic stability of slopes has been a topic of considerable interest in geotechnical engineering for the past 30 years. During that period the state of practice has moved from simple pseudo-static analyses to more complicated permanent displacement analyses. However, it is known that post-earthquake serviceability is more related to permanent displacements induced by shaking, than to the factor of safety. Newmark developed a simple procedure for estimation of permanent slope displacements that develop during seismic shaking, widely used by geotechnical engineers for a long time. The present work is essentially based on results of seismic response analysis of a high (130m) earthfill dam with central clay core. Given that a 2D FE plane strain model has been adopted for dynamic analyses of 3 different dam cross sections and that non-linear behavior of dam and foundation materials is modeled via equivalent linear materials with hysteretic damping, there is no possibility to obtain coupled permanent displacements. The assessment of permanent slope displacements is approached by two decoupled methodologies: a) methodology of Makdisi & Seed (1978) oriented for earthfill and rockfill dams of rather low to medium height, and b) a modified Newmark oriented methodology, based on a mean acceleration time history resulting from a potentially sliding mass. Permanent displacements for each potential sliding mass are calculated with double integration of the difference between acting and critical acceleration. The results of both decoupled methodologies are compared and it is concluded that in some cases permanent displacements are similar irrespective of the methodology used, but there are also other cases where results are severely divergent. Critical evaluation of all results and confrontation with results of coupled analyses of effective stresses from international bibliography, allow a realistic approach of expected displacements as an upper limit crudely approximated.

## SEISMIC RISK ASSESSMENT FOR BELI ISKAR DAM – ID 812

*G. Varbanov, CLSMEE, Bulgaria*
*M. Kostov, CLSMEE, Bulgaria*
*D. Stefanov, CLSMEE, Bulgaria*
*A. Kaneva, CLSMEE, Bulgaria*
*N. Koleva, CLSMEE, Bulgaria*

Beli Iskar gravity dam is constructed more than 60 years ago. The structure is situated high in Rila mountain in seismic active region. During the exploitation period the seismic environment of the construction site has been reassessed and the magnitude of the expected seismic excitation increased. Due to the exposure to the severe environmental conditions the mechanical properties of the constructive concretes have been changed too. From the other hand the regulations and codes that are in force now differ considerably from those that have been in force during the design and construction of the dam. Due to the great difference between the initial design conditions and loads and the present code requirements and material mechanical properties an probabilistic analysis was performed in order to take into consideration all capacity reserves of the structure. The performed estimation is based on the realistic assessment of the seismic hazard for the region, statistically defined material properties and loads. The basic ideas of the methodology for performing a Probabilistic Safety Analysis (PSA) for Nuclear Power Plants are applied in the investigation. To assess the statistical characteristics of structures behavior under seismic excitation the "Latin Hypercube Experimental Design" (LHCED) procedure is used. The most dangerous dam failure scenarios are defined and are prioritized according to the respective seismic risk. In the proposed paper is discussed the assessed of the seismic risk for as-built status of Beli Iskar dam as well as after the implementation of the upgrading measures. Based on these results the efficiency of the proposed upgrading is proved. The estimated values are compared with the seismic risk calculated for other similar concrete dams.

## STRONG MOTION INSTRUMENTATION OF DAMS - A TOOL FOR SEISMIC HAZARD REDUCTION – ID 828

*V. Mihailov, IZIIS-Skopje, Macedonia*
*D. Dojcinovski, IZIIS-Skopje, Macedonia*

A high dam is a particularly important element in seismic risk evaluation of the wider dam site area, i.e., in the definition of the seismic risk of the area an which a dam is planned to be constructed. A large number of high dams in the world and in our country are located within high seismicity zones or in zones close to areas which were affected by string earthquakes in the past. The earthquake phenomenon involves almost always numerous problems which cannot be solved exactly due to the lack of instruments for recording earthquake intensities and response of structures. Without such a record, damage and behaviour of structures during strong earthquakes cannot be compared to the seismic design criteria nor proper decisions concerning rational repair and reconstruction could be made. Data on the ground motion during earthquakes to which dams are exposed and behaviour of dams are fundamental for seismic hazard evaluation, definition of design parameters and criteria and for all other dynamic investigations in earthquake engineering. Without such data all investigations and analysis that follow would be based on assumptions. The irregularity in earthquake occurrence makes difficult the possibility to obtain immediately the most useful data. One of the possible ways to solve these problems is to establish a network of a greater number of instruments for recording ground motion and response of structures during strong earthquakes. The main objective in seismic monitoring of structures (high-rise buildings, dams, power plants, bridges etc.) is to facilitate response studies that lead to improved understanding of the dynamic behavior and potential for damage to structures under seismic loading. In this paper attention will be concentrated on code requirements for instrumentation of dams, experience, and results obtained from strong motion network in Macedonia.

## HAZARD MODELS IN THE CENTRAL PART OF ROMANIA FOR DAM'S RATING IN SEISMIC RISK CLASSES – ID 829

*I. A. Moldovan, National Institute for Earth Physics, Romania*
*E. Popescu, National Institute for Earth Physics, Romania*

Main goal of this paper is rating all dams from central part of Romania into seismic risk classes. Risk classes can be used to establish the necessity of detailed assessment of seismic safety of the dams and to establish the priorities of these evaluations. Methodology which is used in this paper offers an easy way to evaluate the most vulnerable hydrotechnical facilities among the multitude of the central-Romanian dams, that are affected by intermediate-depth Vrancea earthquakes and local crustal earthquakes from Fagaras, Campulung, Sinaia and Transylvanian Deppression. The risk is expressed as a product between hazard and vulnerability. In particular, seismic risk in the case of hydrotechnical arrangements is computed as a product between seismic hazard (corresponding to the location of the respective hydrotechnical arrangement) and the seismic vulnerability of the respective arrangement. Various risk factors and weighting points can be used to approximately quantify the Total Risk Factor (TRF) of any dam [Bureau and Ballentine, 2002]. The TRF depends on the dam type, age, size, the downstream risk potential, and the dam vulnerability, which depends on the seismic hazard of the site. The dam structure influence is represented by the sum of capacity, height, and age risk factors. The downstream hazard factor is based on population and property at risk. The vulnerability rating is a function of the site-dependent seismic hazard and observed performance of similar dams, as defined by a predicted damage factor.

## EFFECT OF NON-UNIFORM GROUND MOTION ON SEISMIC RESPONSE OF ARCH DAMS – ID 873

*A. Jalali, University of Tabriz, Iran (Islamic Republic Of)*

*A. Zamani, University of Tabriz, Iran (Islamic Republic Of)*

Seismic analyses of most of the structures typically use uniform, free field ground motion at the foundation interface as the seismic input motion. However, significant variation in amplitude and phase can occur along the interface if its spatial extent is of considerable size; this is certainly true for long span bridges and large dams. Reliable analytical procedures to predict seismic response of concrete arch dams are essential to design of earthquake resistant dams or in evaluating the seismic safety of existing dams. The rigorous seismic safety evaluation of arch dams must consider effect of dam-foundation rock interaction; dam-water interaction, and spatial variations in ground motion. Extensive research on seismic response of arch dams during last four decade has shown importance of all of those on dam behavior. The state of art in computing the earthquake response of an arch dam by using substructure method uses finite element idealization for dam body, direct boundary element method for determining frequency dependent impedance matrix for foundation region and finite element mesh for complicated shape of the reservoir. Uniform input motion is considered as earthquake loading for dam-foundation-water system(EACD-3D-96). In this research, the possibility of including non-uniform input motion at the interface of dam and foundation has been incorporated in the EACD-3D-96. The response of Pacoima dam and acceleration of the canyon were recorded in Northridge earthquake by a network of CDMG accelerometers. The strong motion accelerograms provide a unique opportunity to examine actual behavior of the dam subjected to a large earthquake with non-uniform input. Analysis of Pacoima dam is performed for both uniform and non-uniform input motions. The important effects of non-uniform input motion, sometimes leading to a decrease and sometimes to an increase, has been quantified by comparing arch and cantilever stresses in both cases.

## ASSESSMENT OF DYNAMIC PERMANENT DEFORMATION OF EARTH DAMS USING NEWMARK AND DECOUPLED METHODS – ID 1054

*Y. Jafarian-Marzouni, iran university of science and technology, Iran (Islamic Republic Of)*
*M. H. Baziar, iran university of science and technology, Iran (Islamic Republic Of)*

Dynamic permanent deformations of eight Iranian earth dams have been compared using Newmark sliding block model and decoupled methods. All of these dams are inhomogeneous in sections and over 60m in height. Decoupled method was carried out using an equivalent linear method implemented in finite element analysis. To implement this task, several major earthquakes recorded in Iran are used. Afterwards, Newmark sliding block method was applied to calculate the permanent deformation considering the effect of amplification in these dams. Comparison of the findings reveals the difference between the results of these two methods depends on the natural period of dams to mean period of ground input motions ratio (Ts/Tm), especially when the ratio is approaching unity. Besides, the results of decoupled method were compared to the Makdisi and Seed (1978) chart that was obtained from decoupled analyses of those homogeneous embankments from 30 to 60m in height using American earthquake records.

## INFLUENCE OF DYNAMIC PORE PRESSURES ON THE SEISMIC RESPONSE OF GRAVITY DAMS – ID 1075

*T. Lazaridis, University of Bristol, UK*
*C. Taylor, University of Bristol, UK*

A key feature of the seismic performance of concrete gravity dams, about which there is considerable uncertainty, is the hydro-mechanical behaviour of pore fluid in a jointed rock foundation. This paper will explore this phenomenon using a distinct element analysis approach that explicitly models the presence and dynamic flow of pore water in a variety of gravity dam-foundation scenarios under seismic loading.

The paper will demonstrate that neglecting fluid flow, and only allowing for pore pressure increases due to fluid compressibility, can lead to grossly conservative outcomes in the form of continuous sliding of the dam downstream. It will be shown that localised fluid flow is an important factor, alongside cavitation, even though the duration of seismic loading is relatively short.

Unfortunately, a fully coupled, non-linear, hydro-mechanical seismic model is a major computational effort, since the time step is governed by the stiffness of the pore fluid, which is an order of magnitude greater than the surrounding rock or concrete. A fully coupled model is probably not economically viable for normal dam safety analyses, but may become so as computational power increases. Alternative simplifications to the distinct element model, which seem to produce reasonable approximations to the fully coupled model, will be discussed, alongside several important detailed modelling issues.

## RESERVOIR INDUCED EARTHQUAKE ACTION AND CRUSTAL MOVEMENTS – ID 1204

*J. Snæbjornsson, University of Iceland, Iceland*
*C. Taylor, University of Bristol, UK*
*B. Stefansson, Landsvirkjun, Iceland*
*R. Sigbjornsson, University of Iceland, Iceland*

In 2003 the construction of the Kárahnjúkar Hydroelectric Project was initiated in eastern Iceland. A key component of the project is the 2100 million m3 Hálslón reservoir, created by construction of three dams. The largest dam is the Kárahnjúkar Dam, a 200 m high concrete face rockfill dam with a volume of 8.5 million m3. The auxiliary dams are 25 and 60 m high moraine core dams founded on soft soils and rock, respectively. In terms of tectonic activity, the area was considered to be east of the Northern Neovolcanic Zone in Iceland and generally assessed as an area of low seismicity. The excavation of the foundation for the main dam in the spring of 2004 revealed more extensive faulting than expected in the plinth of the dam, and further studies of the area revealed additional faults, some of which had slipped during Holocene. In response to these findings, the earthquake hazard in the Hálslón Area was reviewed with special emphasis on near-field events corresponding to this additional information on faults and the general geology of the area. Furthermore, an exploratory study was initiated to investigate quasi-static crustal movements induced by reservoir impounding and primarily driven by changes in pore pressure in underlying rock. The analysis considered a simplified 2-D cross-section across the valley system adjacent to, and slightly upstream of, the two main dams. The distinct element method was applied in the modelling the rock fault systems. The results from the numerical study of the behaviour of this system during impounding of the reservoir are presented. Further, the associations between reservoir impounding, pore pressures, reservoir induced seismicity and fault displacements are studied and discussed. The objective is to provide a credible assessment regarding the overall fault displacements induced by the reservoir impounding.

## MODAL IDENTIFICATION OF LARGE CONCRETE DAMS USING RANDOM-DECREMENT TECHNIQUES – ID 1494

*P. Mendes, ISEL, Portugal*
*S. Oliveira, LNEC, Portugal*

In large concrete dams the ambient vibrations can be used for the modal identification of the dynamic structural characteristics. However, the high stiffness of these structures implies low amplitude measurements what requires the use of appropriated methodologies in order to enhance the real structural behaviour from the collected data.

The use of random decrement techniques to filter the collected data can be useful as a pre processing treatment in order to make a reasonable modal identification using the usual techniques, as peak picking (PP) or frequency domain decomposition (FDD).

This work presents the application of these techniques for modal identification using some results of dynamic measurements carried out at Cabril dam, the highest Portuguese arch dam, under operational conditions.

### PRACTICAL ISSUES IN FINITE ELEMENT ANALYSIS OF CONCRETE GRAVITY DAMS UNDER SEISMIC LOADS – ID 1586

*A. R. Manafpour, Halcrow Group Limited, UK*
*A. C. Morison, Halcrow Group Limited, UK*
*S. C. Gallocher, Halcrow Group Limited, UK*

Despite the existence of long established methods for the design of gravity dams under static loads, practical finite element modelling and the application of seismic design criteria using current guidelines remains a challenging exercise.

The explosive growth of numerical capabilities during the past decade has made it possible to consider more complex analysis approaches during the design process. However this step change has introduced a new set of design issues for engineers, partly due to diversity of available methods but largely due to the plethora of input and output parameters required and generated during each analysis. The consequence of this is considerable time and resource needing to be spent to achieve confidence in the results.

In this paper some theoretical issues in seismic analysis of gravity dams are reviewed with the main focus on the definition of an acceptable structural model that can adequately capture the main dynamic characteristics of the system and make reasonable representation for fluid-dam-foundation system. A practical application is considered using a gravity dam example and two different software packages; DIANA and EAGD-SLIDE. Each software has its own analytical approach and inherent assumptions. Various time history analyses are carried out to address the effect of issues such as water compressibility, reservoir boundaries, element types, foundation stiffness and inertia interaction, and differences between horizontal and vertical ground motions.

The results of the comparative study are presented in terms of peak displacement response as well as time history of crest displacements. It was shown that under considerable seismic forces it is necessary to account for more rigorous representation of dam-foundation interaction and boundary conditions. Initial consideration with regard to specifying important analysis parameters is an essential step in selecting appropriate analysis approach, assumptions and software, which will eventually result in considerable savings in time and resources.

### SEISMIC ANALYSES OF GRAVITY DAMS IN NARROW VALLEYS: RUDBAR-LORESTAN RCC DAM – ID 1590

*A. R. Manafpour, Halcrow Group Limited, UK*
*Y. Y. Chen, Halcrow Group Limited, Ukraine*
*A. C. Morison, Halcrow Group Limited, UK*
*S. C. Gallocher, Halcrow Group Limited, UK*

Gravity dams are built as independent monoliths separated by vertical contraction joints. For relatively long and straight dams the analytical behaviour may be idealised as two dimensional models of dam-water-foundation system. Inherent strength and stiffness of these dams in cross valley direction is considered to be significant so that it is not necessary to consider the seismic performance under earthquake acting in that direction. However for gravity dams within narrow valleys three-dimensional behaviour should also be considered using 3D models.

In this paper the seismic design issues for gravity dams in narrow valleys are reviewed with reference to those considered in 158m high Rudbar-Lorestan RCC dam in Iran. The dam has a length to height ratio of between 0.5 and 1 at the base and crest level, respectively. The abutments at two sides of the valley have a steep slope of about 1:5. Two and three-dimensional analyses have been carried out to provide an understanding of structural behaviour of the dam-water-foundation system under static as well as extreme seismic loads. 3D analyses account for nonlinear behaviour of contraction joints during the seismic event. Main specifications of the models are discussed and some analysis results are reported. It is shown that some complexities may arise during dynamic analysis for those blocks positioned on steep slopes.

## ES 3a: Structural Engineering - Analysis
Level-1

### THE DUCTILITY DEMAND AND NONLINEAR TORSIONAL RESPONSE OF SYMMETRIC PLAN STRUCTURES WITH INFILL WALLS – ID 6

*D. Guney, I.T.U., Turkey*
*H. Boduroglu, I.T.U., Turkey*
*E. Aydin, I.T.U., Turkey*

Discrepancies between with infill walls and without infill walls of the structural floor stiffness imply that a building nominally symmetric plan is actually asymmetric to some unknown degree and will undergo torsional vibration when subjected to purely translational ground motion. In this study, the behavior of torsional earthquake response of symmetric structure was investigated. Generally during the design procedure, the stiffness distribution of the infill walls of structures is not considered. These infill walls have an initial stiffness which cause torsional responses even the structure is symmetric. If the structure is asymmetric, these walls change torsional response of structures. This paper shows that for generalized symmetric plan buildings, the reduction of in the building strength resulting nonlinear torsion can be obtained. In order to investigate this effect, different types of structures are modeled with different structural plan combination. The nonlinear behavior of both infill walls and structure assumed as bilinear force-displacement relation. Earthquake records were applied to both asymmetric and symmetric structures then the nonlinear response characteristics of the structures were calculated in time history domain. In order to calculate nonlinear response of structures, an algorithm of program was written for Mathematica. The basis of algorithm was using State Space Method in order to calculate dynamic response characteristics of structures under earthquake motions. The response results were compared. According to these results, the effects of infill walls to the nonlinear torsional response of structure and asymmetric stiffness distribution were interpreted

### THE NONLINEAR TORSIONAL RESPONSE OF STRUCTURES UNDER EARTHQUAKE EFFECT WITH ROTATIONAL COMPONENT – ID 7

*D. Guney, I.T.U., Turkey*
*H. Boduroglu, I.T.U., Turkey*
*E. Aydin, I.T.U., Turkey*

Discrepancies between with infill walls and without infill walls of the structural floor stiffness imply that a building nominally symmetric plan is actually asymmetric to some unknown degree and will undergo torsional vibration when subjected to purely translational ground motion. In this study, the behavior of torsional earthquake response of symmetric structure was investigated. The infill walls which have an initial stiffness which cause torsional responses even the structure is symmetric. If the structure is asymmetric, these walls change torsional response of structures. This paper shows that for generalized symmetric plan buildings, the reduction of in the building strength resulting nonlinear torsion can be obtained. In order to investigate this effect, different types of structures are modeled with different structural plan combination. The nonlinear behavior of both infill walls and structure assumed as bilinear force-displacement relation. Earthquake records are generally applied to structures along longitudinal direction. However an earthquake has six different components. Three of them are longitudinal, others are torsional. If the structure foundation is stiff, these components can be takes as two longitudinal and one rotational. This rotational component can not be measured just can be calculated. In order to calculate this effect, two parallel acceleration records are needed. These earthquake components are applied to both asymmetric and symmetric structures then the nonlinear response characteristics of the structures were calculated in time history domain. In order to calculate nonlinear

response of structures, an algorithm of program was written for Mathematica. The basis of algorithm was using State Space Method in order to calculate dynamic response characteristics of structures under earthquake motions. The response results were compared. According to these results, the effects of infill walls to the nonlinear torsional response of structure and asymmetric stiffness distribution were interpreted.

### DETECTION OF THE ECCENTRICITY VARIATION IN NONLINEAR RESPONSE USING ARTIFICIAL NEURAL NETWORKS – ID 39

*N. Bourahla, University of Blida, Algeria*
*T. Boukhemacha, University of Blida, Algeria*
*S. Tafraout, University of Blida, Algeria*

In seismic design, the eccentricity is considered as a constant parameter. However, during the seismic excitation uneven yielding of the lateral resisting elements may occur because of unforeseen differences and uncertainties in the resistance limit of some of the elements or because of non uniform geometric distribution of the elements in a non-symmetric structure. This can provoke transitory variation of the eccentricity level which may lead to unpredicted torsional coupling. Therefore, nominally symmetric structures may behave like an eccentric structure under severe earthquake loading. This effect is accounted for within the context of accidental eccentricity using a constant percentage of the building dimension perpendicular to the direction of excitation regardless of the type of the lateral resisting system. In previous work this issue has been addressed using a global approach based on neural networks to evaluate the eccentricity from linear displacement responses. The method has been successfully applied to extract eccentricity parameter from ambient vibration records. In this paper, the method is extended to evaluate the eccentricity level, from only output data in the time domain, when the structure undergoes large nonlinear deformation. To this end, displacement responses of simple structural models are obtained from nonlinear dynamic analysis and used to constitute a database to train and test a backpropagation neural network. A wavelets-based technique was used to corroborate the results obtained by the neural network. In practice this technique can be used to investigate the behaviour of instrumented buildings subjected to real earthquakes in order to assess the effect of the variation of the eccentricity during severe ground motion.

### ESTIMATING SEISMIC DEMANDS OF BUILDINGS IN IRAN USING ADAPTIVE PUSHOVER ANALYSIS – ID 44

*A. Shooshtari, Ferdowsi University of Mashhad, Iran (Islamic Republic Of)*
*H. Sabaghian, Iran (Islamic Republic Of)*

Every year several earthquakes occur in Iran. Unfortunately some of them cause major damages to infrastructures and buildings as well as many casualties. In order to design earthquake resistant buildings in Iran, seismic demands must be estimated. In this paper, based on Iranian codes for design of concrete structures and for earthquake resistant buildings several have been designed. These buildings have been analyzed using the new approach of modal inelastic static analysis (adoptive pushover analysis) to predict their seismic behaviors. Pushover analysis has been gaining significance, as a tool, for assessment and design verification. However it has been shown by many researchers that despite of its efficiency and applicability, it also exhibits significant limitation. For example, the deformation estimated can be highly inaccurate, if higher mode effects are important. In this study, a new enhanced pushover methodology, which tries to mitigate some of the inherent limitations of usual pushover procedures, is used. The suggested approach considers the current stiffness state and modal properties of the structure at various levels of inelasticity to update the lateral load distribution along the height. Additionally site-specific spectra can be taken into account for the scaling of the forces. It is shown that the new approach yields nonlinear static analysis results very close to inelastic time-history analysis. The results showed that response modification factor for buildings introduced by Iranian code must be modified based on site specification as well as type of ductility ratio that has been expected from the seismic behavior of buildings.

### RESPONSE OF BASE-ISOLATED BUILDINGS INCORPORATING FLUID VISCOUS DEVICES TO NEAR-FAULT EARTHQUAKES – ID 50

*S. Sorace, University of Udine, Italy*
*G. Terenzi, University of Florence, Italy*

Silicone fluid viscous devices can be effectively incorporated in the base-isolation systems of building structures to provide an optimal passive control of their seismic response. This combined base-isolation/supplemental damping technology has been for many years the topic of research studies of the authors, also developed within EC-funded international Research Projects. The experimental characterisation, analytical and computational modelling, formulation of design procedures, and practical implementation of this protective system in actual buildings, were particularly developed within these studies. Some investigations on the effects of near-fault earthquakes were also carried out, but without reaching yet conclusive results. In the paper that will be submitted for the presentation to the ECEES Conference, a comprehensive new analysis of these effects is offered. This analysis will be articulated on the following steps: a) evaluation of the spectral response of SDOF systems incorporating the considered technology to the two main near-fault ground motion models proposed in the literature, i.e., the "cycloydal" pulses and the "forward-and-back" pulses generated from blind-thrust fault simulations; b) comparison of the obtained spectra with the corresponding curves derived from Eurocode 8-generated artificial accelerograms and real seismic records; c) application of the most critical near-fault signals highlighted by the spectral analysis to the structural models of two actual case studies, represented by two Italian buildings protected by the considered techology (the first of which already designed, and the second one currently in the preliminary design stage); d) final evaluation of the near-fault earthquake effects based on the results of the non-linear dynamic analyses carried out at point c).

### FINITE ELEMENT ANALYSIS OF FIXING THE STEEL PLATE WITH BRACES ON BEHAVIOR OF RETROFITTED RC BEAMS – ID 52

*G. Arslan, Yildiz Technical University, Turkey*
*F. Sevuk, Yildiz Technical University, Turkey*
*I. Ekiz, Yildiz Technical University, Turkey*

Almost all researchers studying in this field agree on the significant contribution of using epoxy-bonded continuous horizontal steel plates on load carrying capacity of reinforced concrete (RC) beams with rectangular cross-section. However, there is not enough data available on the effect of I-shape jacket at the end of flexural steel plates (fixing the steel plate with braces) and there is no consensus on the contribution I-shape jacket to this type of beams within the limited available data. In this study; the use of end anchorage technique such as I-shape jacket is investigated and having the different distance of fixing the steel plate with braces from mid-span are evaluated. Using the analytical model “Drucker-Prager”, which are proven by the experimental studies and changing the distance of fixing the steel plate with braces from mid-span, analytical solutions are provided; then the load-deflection curves are compared and some comments are made on.

### GENERALISED SEISMIC-INDUCED STRUCTURAL DAMAGE PREDICTION USING ARTIFICIAL NEURAL NETWORKS – ID 54

*O. De Lautour, University of Auckland, New Zealand*
*P. Omenzetter, University of Auckland, New Zealand*

The ability to assess the vulnerability of civil infrastruc-

ture to earthquake-induced damage is undoubtedly one of the most important challenges faced by structural engineers. Contemporary methods of estimating the extent of seismic induced damage include nonlinear finite element analysis and the use of seismic vulnerability curves. Both these methods however, are limited to predicting damage to a certain predetermined structure or class of structures characterized by a small number of parameters. As such, they are unable to generalise damage information to a wider range of other structures, e.g. with a different number of stories and/or bays or different ground motions.

This study presents a generalised method of structural damage prediction utilizing Artificial Neural Networks (ANNs). ANNs are used to relate a set of input variables, describing both the structure and the ground motion, to a damage index describing the extent of damage in the structure. Applied to non linear computer models of simple 2D reinforced concrete frame buildings, the ANN was capable of accurately predicting damage to frames varying in strength, stiffness, damping and geometry whilst subjected to a range of ground motions with different peak accelerations, velocities, displacements and spectrum intensities.

This generalised approach provides a major development over contemporary methods and gives a good balance between accuracy and time efficiency. Further development, into more realistic structures, e.g. considering 3D effects, would provide a useful tool for natural hazard mapping and emergency response planning.

## EVALUATION OF NONLINEAR STATIC ANALYSIS FOR ESTIMATING OF TARGET DISPLACEMENT – ID 64

*A. Keyvani, Iran (Islamic Republic Of)*

Nonlinear static analysis is one of analyze in Guideline for the Seismic Rehabilitation of Existing Buildings which uses Displacement Coefficient Method for to calculate maximum displacement in roof of structure. In this procedure, maximum displacement calculated by effective period of structure, response spectrum of earthquake and also coefficients that proposed in this Guideline. In this paper, we evaluate the efficiency of this procedure for to estimate value of maximum displacement in roof of buildings with special steel moment frames. For this study, several buildings with special steel moment resisting frames have been modeled in Perform3d. Nonlinear dynamic procedure has been used for analysis. Results show that maximum displacement that estimated by the Displacement Coefficient Method are more than maximum displacement that calculated by nonlinear dynamic analysis.

## EVALUATION OF THE CONTROLLING OF INTER-STORY DISPLACEMENT IN THE IMPROVEMENT OF VULNERABILITY – ID 65

*A. Keyvani, Iran (Islamic Republic Of)*

Special steel moment frames are one of the lateral resisting systems that proposed in Iranian Seismic Standard (STANDARD NO.2800). These systems have high ductility and will cause high displacement in their stories. Therefore, displacement of stories affects on the design of these systems. In this paper, we assess effect of the controlling of displacement on vulnerability of buildings with special steel moment frame system. For this assessment, we designed several special steel moment resisting frames under the STANDARD NO.2800 requirements. To be concluded, the vulnerability of these frames has been controlled by Guideline for the Seismic Rehabilitation of Existing Buildings. Results of the study show that controlling of displacement improves vulnerability of the columns in inside bay.

## PUSHOVER ANALYSIS OF REINFORCED CONCRETE BUILDINGS WITH FLEXIBLE FLOOR DIAPHRAGM – ID 75

*S. K. Deb, Indian Institute of Technology Guwahati, India*
*V. K. Geddam, TCE, India*

The nonlinear static procedure or pushover analysis is a simple option for estimating the strength capacity of reinforced concrete building in the post-elastic range. This procedure involves applying a predefined lateral load pattern, which is distributed along the building height. The lateral forces are then monotonically increased in constant proportion with a displacement control at the control node of the building until a certain level of deformation is reached.

In seismic analysis of buildings it is common to assume that the floors are rigid in their own plane. Even though, this assumption is good for most of the buildings, there are situations where diaphragm flexibility is significant. This in-plane floor flexibility is significant particularly for long narrow buildings and buildings with stiff end walls. The floor diaphragm flexibility can alter the dynamic properties of a building from that obtained using rigid diaphragms idealization and will obviously affect the lateral load distribution along the height of the building, and also influences the lateral load distribution among various vertical members, i.e., frames and walls.

However, the pushover analysis of such buildings has not been addressed in the literature. In this paper, step-by-step procedure for pushover analysis of reinforced concrete buildings with flexible floor diaphragm has been presented. The prime focus of this paper is to investigate the difference in the results of pushover analysis based on the rigid floor idealization and flexible floor idealization of a sample building with flexible floor for three different lateral load patterns. Results indicate that the frame displacements have been reduced for flexible floor diaphragm idealization as compared to those for rigid floor diaphragm idealization. A considerable change in profile of column moments is observed for flexible floor diaphragm idealization.

## LOADING DISCONTINUITY AND ITS REMEDY FOR STEP-BY-STEP SOLUTION OF SHOCK RESPONSE – ID 80

*S. Y. Chang, National Taipei University of Technology, Taiwan*

It has been analytically verified that the discontinuity at the end of an impulse might lead to numerical inaccuracy since it will result in an extra impulse and thus an extra displacement in the time history analysis. Apparently, this difficulty can be overcome by using a very small time step to reduce the extra impulse and hence extra displacement so that an accurate solution can be achieved. However, the computational efforts involved might be significantly increased since this small time step is performed for a complete step-by-step integration procedure. To effectively overcome this difficulty, an approach is proposed to reduce the extra impulse and hence the extra displacement. In fact, the proposed approach is to perform a very small time step immediately upon the termination of applied impulse since the extra impulse introduced by the discontinuity is proportional to the discontinuity value at the end of the impulse and the size of integration time step. The feasibility of this approach is analytically proved. Furthermore, numerical examples are used to confirm the analytical results.

## 3D FINITE ELEMENT MODELING OF TOP AND SEAT ANGLE – ID 116

*F. Danesh, K.N.Toosi University, Iran (Islamic Republic Of)*
*A. Pirmoz, K.N.Toosi University, Iran (Islamic Republic Of)*

In this study the moment-rotation behavior of bolted top and seat angle with double web angle connections under monotonic loading are studied. Several 3D parametric finite element models are presented where the geometrical and mechanical properties of connections are as parameter. The effect of all component interactions, such as slippage of bolts, bolts pretension and friction coefficient, contact surface algorithm between all adjacent surfaces is included in this research. To confirm the moment – rotation relationship, numerical results are compared with test results using different data and properties of experimental works that has been done by researchers. In addition the results are compared with mathematical formulation suggested by many researchers. The results of numerical modeling have good agreement with test results.

The study is further extended with investigating the effect of this flexible connection on global behaviour of moment resisting frame. For this purpose, the moment resisting frame using this type of connection instead of rigid connection was designed. In this frame all connections are modeled as joint elements with moment-rotation relationship that are derived from numerical results. To consider the dynamic behaviour of this type of structure, three earthquake excitations were selected and the designed frame was subjected to these records. The global behavior of this frame is compared to that behavior of special moment resisting frame. In this comparison the capacity and global ductility of these two types of structures are presented and discussed.

Key words: Semi-rigid connection; Bolted connection; moment resisting frame; numerical modeling.

## RETROFITTING AND STRENGTHENING QUALITY EVALUATION FROM RIGIDITY VARIATIONS OF A DAMAGED BUILDING – ID 121

*M. N. Farsi, CGS, Algeria*
*J. L. Chatelain, IRD, France*
*B. Guillier, IRD, France*
*S. A. Zermout, CGS, Algeria*

The rigidity of a six-story shear wall building, damaged by the May 21, 2003 Boumerdes (Algeria) earthquake is evaluated before the event, in its damaged state, and after retrofitting, using the estimation of the frequency and damping factor of the structure. The pre-event parameters are estimated through a numerical analysis, based on the structure drawings, together with a micro-tremor investigation of an identical non-damaged building located on the same site. The damaged and retrofitted parameters have been obtained using micro-tremor recordings on the studied building. The variation of the frequency and damping factor during the three stages the building went through allows to evaluate its rigidity changes, and therefore to control the quality of retrofitting and strengthening.

Key words: retrofitting, strengthening, frequency, damping, Boumerdes

## A CRITIQUE OF VARIOUS MISSING MASS CORRECTION METHODS FOR SEISMIC ANALYSIS OF STRUCTURES – ID 134

*D. Meera Kaviyad, Royal Bhutan Institute of Technology, Bhutan*
*P. R. Bose, Delhi College Engineering, India*

The truncation of higher modes leads to the "missing mass" effect in the seismic analysis of structures by modal synthesis method. Various techniques have been developed to take the effect of the "missing mass" contained in the uncalculated higher modes into account. This paper discusses various missing mass correction methods, viz, Static Correction method, mode acceleration method and residual mode method in detail. The methods are compared with the help of simple examples by evaluating the dynamic response of the system for El Centro (1942) ground acceleration. The residual mode method is found to be superior to other methods for the seismic analysis of structures using response spectrum method.

## EFFECT OF MODE TRUNCATION IN SEISMIC ANALYSIS OF BUILDINGS: PHYSICAL INTERPRETATION – ID 135

*D. Meera Kaviyad, Royal Bhutan Institute of Technology, Bhutan*
*P. R. Bose, Dehli College of Engineering, India*
*A. Verma, Dehli College of Engineering, India*

Modal analysis or mode super position method has become a standard tool, for calculating the dynamic response of viscously damped linear dynamic systems with classical damping. The method is widely used, uncouples a set of N second degree differential equations governing the dynamic behavior of N degree of freedom systems. Solution becomes that of a collection of N independent differential equations convenient for computation. It is generally considered that in regular building structures that have uniform mass and stiffness distribution, only a few lower order modes are sufficient to evaluate the total response with reasonable accuracy. Consequently, the higher modes can be truncated. The premise of the seismic design methodology in a typical building code is based on the consideration of a single mode. The modal analysis procedure for calculating the dynamic response of viscously damped linear dynamic systems with classical damping is reformulated with the objective of providing a useful physical interpretation of mode truncation. It is observed that even in regular buildings the truncation of modes can lead to the over estimation or under estimation of response. To illustrate this, numerical results are presented for a five storey building frame.

## INVESTIGATION OF THE CONCEPT OF GROUND VELOCITY INCREMENT, DV AND ITS EFFECTS ON THE NONLINEAR DISPLACEMENT RESPONSE OF SDOF SYSTEMS – ID 143

*B. Ozturk, Nigde University, Turkey*

The main interest of this study is the investigation of the ground velocity increment, DV concept and the definition of how it characterizes the nonlinear displacement response of single-degree-of-freedom (SDOF) systems. Accordingly; the relationship between the ground velocity increment, DV and the maximum nonlinear displacement response are investigated. On the basis of the earlier works of Westergaard (1933) and Newmark (1975); a new methodology is developed in order to estimate the nonlinear displacement of a single-degree-of-freedom (SDOF) system considering the effects of impulsive loading on the system. Regarding the effects of the ground velocity increment, DV the maximum nonlinear displacement response, Dm is evaluated.

## INVESTIGATION OF FRAME AND SHEAR WALLS INTERACTION ON THE FLEXIBLE FOUNDATION – ID 147

*S. Nayeri, Tabriz university, Iran (Islamic Republic Of)*
*A. Davaran, Tabriz university, Iran (Islamic Republic Of)*
*A. Kashefi, Tabriz university, Iran (Islamic Republic Of)*

Shear walls are used as an efficient structural system for resisting against external lateral loads such as wind and earthquake loads. Regarding to this fact that the pervious studies in the behavior of shear wall system were performed without considering the effect of foundation and interaction between soil and structure. So it seems necessary to conduct some research in the evaluation of interaction between frame and shear wall on the flexible foundation, considering the effect of soil-structure interaction.

A non-linear static and dynamic modeling of a frame- shear wall system rested on flexible foundation is conducted which is accompanied with the modeling of soil by Winkler 's springs under foundation. The dynamic behavior of shear wall system is assessed. The results obtained show that depending on types of soil under flexible foundation, the values of displacements are higher than displacements when the flexibility of foundation is ignored and the effect of interaction between frame and shear wall is decreased. Also the internal forces at the base of shear walls differ significantly between two cases.

Keywords: Non-linear Dynamic Analysis; Shear walls; Flexible foundation; Soil-Structure

## EFFECTIVE LENGTH OF IRREGULAR FRAME COLUMNS – ID 175

*G. Ozmen, Istanbul Tecnical University, Turkey*
*K. Girgin, Istanbul Technical University, Turkey*
*E. Orakdogen, Istanbul Technical University, Turkey*

Determination of effective lengths of frame columns is one of the significant phases of earthquake-resistant design of the structures. Theoretically, the effective length of an individual

column is determined by calculating the system-buckling load of the frame. Since a full system instability analysis, may be quite involved for frames met in practical applications, the so-called "Isolated subassembly approach" has been developed. In several design codes and specifications, simplified formulae and diagrams based on this approach are given for determining the effective lengths of frame columns. It is shown that these formulae may yield rather erroneous results especially for irregular frames ie. frames with beam discontinuity. This is due to the fact that, the code formulae utilise only local stiffness distributions. In this paper, a simple procedure for determining approximate values for the buckling loads of both regular and irregular frames is developed. The procedure utilises lateral load analyses of frames and yields errors in the order of 5%, which may be considered suitable for design purposes. The effective length values are not strongly dependent on the choice of lateral loading. Hence, any existing lateral loading on the frame under consideration may be used without losing a significant amount of accuracy. The proposed procedure is applied to several irregular examples and it is shown that all the errors are in the acceptable range and almost all of them are on the safe side.

### SEISMIC CAPACITY OF COLUMNS USING NON-LINEAR STATIC PUSHOVER ANALYSIS. – ID 208

*A. Chainani, Faculty of Technology and Engineering, India*

The design concept of earthquake resistant structures has changed recently, from force based to the performance based design because the former design does not address the post yield behavior resulting into unique damages, during severe earthquakes. Performance based seismic design evolved to take care of the damage control under the varying earthquake loadings. Of all the methods that are used conventionally for performance design of building, under earthquake loadings, the uniform deformation control is considered to be more effective, using re-analysis and re-design procedures. So performance based design can be used to predict the seismic performance of building or structural elements of building. Column (vertical structural member) is the main component of building. In this paper an attempt is made to obtain seismic capacity of columns of different shapes, which are used in practice, and safest shape of column is suggested, which shows good seismic performance under earthquake loading and can be used in real practice. The paper also includes the shape comparison based on seismic capacity of column. A typical example of multistoried building is taken. To obtain the seismic capacity of column, a non-linear static push over analysis has been used and capacity curves for all the columns were obtained.

### THE ASYMPTOTIC APPROACH TO SSI - THE COMBINED TIME-DOMAIN AND FREQUENCY-DOMAIN CALCULATIONS – ID 224

*A. Tyapin, Atomenergoproject, Russian Federation*

At the moment one can perform the SSI analysis either in the time domain or in the frequency domain. In the time domain one usually uses a platform model with kinematical excitation and with some "soil" springs and dashpots, modeling the soil foundation impedances. Structural models in such analyses are very detailed enabling the design of structures. However, "soil" springs and dashpots can give only a primitive approximation of actual impedances (especially for a layered media and embedded structures). In the frequency domain one can get an advanced approximation of the SSI effects (e.g., using SASSI) but the structural models are comparatively poor. This is usually enough to get the response spectra, but not enough for the design of structures. The author suggests an asymptotic approach (ideal for the case of the rigid basement). The idea is to calculate the soil-structure interaction contact distributed forces for the rigid basement case in the frequency domain using SASSI and then to perform the time domain calculations using the platform model with the distributed forces load instead of the kinematical excitation. In the SASSI model the upper structure is represented by the special frequency-dependent element accumulating the modal information from the detailed fixed base model of the structure, created for the time-domain calculations. In the time-domain analysis the soil is modeled by the simplified spring-dashpots model, but the external excitation forces are modified so that in the case of the rigid basement motion (got from the SASSI analysis) the total forces acting on the basement from the soil (the sum of the "soil" springs/dashpots response and the external excitation) are equal to those obtained from SASSI. As a result, the simplified soil model actually contributes only for the fluctuations of the final basement motion from the rigid case motion.

### DISTRIBUTION OF BASE SHEAR OVER THE HEIGHT OF ISOLATED BUILDINGS – ID 228

*F. Khoshnoudian, Amirkabir University of Technology, Iran (Islamic Republic Of)*
*B. Mehrparvar, Amirkabir University of Technology, Iran (Islamic Republic Of)*

Current seismic codes assume a triangular distribution of base shear for isolated buildings similar to their fixed-base counterparts. In this paper the validity of such distribution is investigated for isolated structures having elastomeric isolators. So different models of isolation systems are selected that cover a wide range of elastomeric isolators with low to high stiffness and damping. The results of non-linear time-history analysis on these models show some conservatism in code-specified distribution compared with the observed distribution of story forces. Also a new formula is proposed instead of the triangular distribution to make a better estimation of real behaviour of seismic isolated buildings.

### NUMERICAL SIMULATION OF BASE-ISOLATED SYSTEMS SLIDING ON CONCAVE SURFACES – ID 239

*N. Jamali, Wuppertal University, Germany*
*W. Zahlten, Wuppertal University, Germany*

Base isolation is an acknowledged means to reduce the transmission of earthquake accelerations from the ground into the structure. Of particular interest are systems where the bearing slides on a concave surface which produces a self-centering force restoring the building to its original position. While the idea behind the technology is straightforward, the numerical simulation of the structural response is difficult, since the contact between the bearing and the sliding surface changes continually between sticking and sliding in a nonlinear process. The research presented here aims at developing a computational model for base-isolated building which would allow the engineer to simulate the structural response in the time domain in order to find an optimum design of both building and isolator. As a first step towards the desired comprehensive simulation tool a two-degree-of-freedom model has been developed for a one-storey building with two base supports via setting up the coupled differential equations. Assuming a linear variation of the accelerations, an analytical solution has been derived within the time step and implemented in a time-stepping procedure. A correct prediction of the friction force is the prominent factor controlling the quality of the results, so special care has been taken to capture the phase changes from sticking to sliding and vice versa in the base isolator with great accuracy. This would require excessively small time steps with corresponding unacceptably high computing time, so an adaptive time-stepping mechanism has been developed to temporarily refine the time steps when phase changes occur and to return to larger increments afterwards. Benchmarks for harmonic loading verified the basic soundness of the approach. First numerical studies for measured accelerograms gave very encouraging results in predicting in how far the accelerations transmitted into the structure and the corresponding motions in the isolator depend on the properties of the latter.

### THE INELASTIC SEISMIC RESPONSE OF SETBACK BUILDINGS INCLUDING SOIL-PILE FOUNDATION STRUCTURE INTERACTION – ID 252

*W. Widodo, Islamic University of Indonesia, Indonesia*

Fan et. al (1991) stated that under earthquake excitations, the existence of stiff piles may modify the earthquake ground motions. Incorporating the soil-pile foundation interaction in the structural analysis will suspiciously affect on the structural response. Gazetas (1991) investigated the effect of the soil-pile foundation interaction on the dynamic response of the structure, but limited only for a very simple elastic structure. The effects of the soil-pile foundation interaction on more realistic structures, specifically on the setback buildings need to be carried out. Investigation on the effect of soil-pile foundation interaction to the inelastic seismic response of the building have been conducted. The 12-strorey RC frame structure located at the Indonesian Seismic Region-4 was used as for building model. The soil-pile foundation interaction can be modeled by Lumped Parameter Model and has been discussed by Gazetas et.al 1992, Gazetas 1994, Novak and Sharnouby 1983, Bozorgnia and Bertero 2004. The stiffness and damping interaction according to Novack's formula was utilized. Two foundation models i.e fixed and flexible (piles) foundation are considered in this study. The building models then to be excited by an approximate free field earthquake motions. Result of the investigation shows that the structural fundamental period and top horizontal displacement of the setback building are smaller than those resulted from regular building. However, the beam's curvature ductility and beam's damage index in upper stories of the setback building are much higher than those for regular one. The opposite result was found for the lower stories. Effect of the soil-foundation interaction on the inelastic seismic response of RC frame is relatively small.

## INELASTIC SEISMIC DESIGN OF STIFFNESS DEGRADING SYSTEMS – ID 278

*S. Jarernprasert, Paul C. Rizzo Associates, Inc., United States*
*E. Bazan, GAI Consultants, Inc., United States*
*J. Bielak, Carnegie Mellon University, United States*

An analysis is made of the effects of stiffness degradation on the earthquake response of yielding single-story structures. Numerical results indicate that for nonlinear hysteretic structures, stiffness degradation leads to larger ductility demands and larger total displacements than for non-degrading elastic plastic systems. Based on the analyses results, a new procedure is proposed to incorporate degradation into the calculation of the seismic response coefficient or normalized yield force Cy = Vy /W, in which Vy is the yield strength and W the weight of the structure. Following an approach recently developed by the authors (1) the value of Cy for a prescribed ductility demand, is estimated as . C(T) is interpreted as a unreduced spectrum, and n depends on the elastic natural period, T, of the structure and on the level of stiffness degradation. Two ensembles of earthquake records were used as seismic input: the first one consists of 87 accelerograms recorded stiff to medium stiff sites in California and the second set comprises 66 Mexican accelerograms recorded at sites in the soft lakebed region in Mexico City, with a dominant period of approximately 2.0 seconds. This study finds that the impact of stiffness degradation on the required yield of inelastic systems is significantly stronger on soft sites.

## DAMAGE DETECTION AND LOCALIZATION IN EXISTING BUILDINGS UNDER LOW AND MODERATE SEISMIC EXCITATIONS – ID 281

*P. Gundes Bakir, Katholieke Universiteit Leuven, Belgium*
*E. Reynders, Katholieke Universiteit Leuven, Belgium*
*G. De Roeck, Katholieke Universiteit Leuven, Belgium*
*G. Degrande, Katholieke Universiteit Leuven, Belgium*

The aim of this study is to detect and localize damage induced in multi-storey re- inforced concrete structures subjected to low and moderate seismic excitations. For this purpose, a typical residential building from the Marmara region is selected and used subsequently for a numerical simulation. Two alternative scenarios are considered for the building. In the first scenario, it is assumed that the building is a code designed building with a strong column-weak beam philosophy. Consequently, the joint regions of the building are assumed to be rigid. When the building is damaged, the plastic hinges are assumed to form in the beams close to the beam-column joints. In the second scenario, it is assumed that the beam-column joint regions of the building are not confined by transverse reinforcement. Consequently, the building is assumed to have flexible joints and the beam-column joint regions are modeled by rotational springs. The response in the undamaged state is calculated at several points from the finite element model of the building and the modal properties are extracted from these simulated responses using stochastic subspace system identification. In the second stage, two different damage scenarios are applied for the building. For the building with the rigid joints, the stiffnesses of the finite elements adjacent to the joint regions are reduced. For the building with flexible joints, the stiffnesses of the rotational springs are decreased with respect to the stiffness of the rotational springs in the undamaged state. The response is again calculated at several response points using the finite element model and stochastic subspace system identification is used to extract the modal properties. The finite element model is updated iteratively to find the exact loaction of damage and the results are compared for the building models with rigid and flexible joints.

## NEAR-FAULT SEISMIC PERFORMANCE OF COMPOSITE STRUCTURES RETROFITTED WITH ISOLATION DEVICES – ID 309

*C. Providakis, Technical University of Crete, Greece*
*E. Xatzina, Technical University of Crete, Greece*

Base isolation technique based on aseismic design criteria has emerged aiming at reducing the seismic damage by providing adequate ductility to absorb earthquake energy and appropriate stiffness to maintain structural integrity and service ability. Recent studies of base-isolated structures subjected to near-fault (NF) ground motions have proved that the long duration pulses in the range of 1-3 secs can lead to significant seismic responses of isolated structures. This concludes that the seismic behavior of the superstructure such as shear force, acceleration and story drift are larger in NF locations than those exhibited in far away sites from the active earthquake faults. In composite steel-concrete structures, the combined properties of steel and concrete should offer efficient solutions to the design of engineering structures. The greater level of energy dissipation achieved by the use of composite structural members allows an increased applicability to earthquake resistant structures. However, despite the frequent application of composite structures there is much less information on the level of ductility demand imposed on composite structural members during their response to earthquake loading. The nonlinear static procedure known as static "push-over" analysis is now used by the structural engineers as a standard design tool for the estimation of seismic demands and identification of plastic hinge mechanisms for buildings. The pushover analysis is now generally considered to be more realistic in estimating the vulnerability of buildings during earthquakes than the linear procedures commonly contained in current antiseismic codes. A comparative study on aseismic performance of different isolators for composite structures experience NF motions is accomplished in the present paper. Parametric analysis for variations in the design parameters is also presented in this study by using the pushover analysis capability of the commercial software ETABS.

## IMPLEMENTATION AND VERIFICATION OF MASONRY PANEL MODEL FOR INFILLED RC FRAMES NONLINEAR DYNAMIC ANALYSIS – ID 355

*E. Smyrou, ROSE School, Italy*
*C. Blandon-Uribe, ROSE School, Italy*
*S. Antoniou, ROSE School, Italy*
*R. Pinho, ROSE School, Italy*

The effect of the infill panels on the response of RC frames subjected to seismic action is widely recognised and has been subject of numerous experimental investigations, while several attempts to model it analytically have been reported. In this paper, the implementation, within a fibre-based Finite Elements program, of an advanced double-strut nonlinear cyclic model for masonry

panels is described. The accuracy of the model is first assessed through comparison with experimental results obtained from static and pseudo-dynamic tests of large or full-scale frame models. This is followed by a sensitivity study whereby the relative importance of each parameter necessary to calibrate the model is evaluated, so that guidance on the general employment of the latter can be given. Furthermore, representative range of values for the geometrical and material properties of the infill panels have been also defined. Finally, it is demonstrated that the adopted double-strut model, in addition to its relative simple modelling implementation, offers also adequate accuracy not only in representing the global behaviour of the system, but also in capturing some local effects introduced by the frame-infill interaction.

Keywords: infill panels, nonlinear dynamic analysis, earthquake response, model calibration, sensitivity analysis.

## DISPERSION REDUCTION OF SEISMIC NONLINEAR RESPONSES OF A 3 STORIES INFILLED REINFORCED CONCRETE FRAME – ID 398

*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*
*A. Azarbakht, IIEES, Iran (Islamic Republic Of)*

Performance-based design method enables designers to evaluate various performance levels of a structure for a given hazard level environment which consists of four steps: hazard analysis, structural analysis, damage assessment and loss estimation. The structural analysis responses are formulated by statistical analysis of the results of the set of non-linear time-history analysis of typical structures for the expected earthquake. Although mean inelastic displacement ratios are very important, it is equally important to quantify its scattering and dispersion which usually display large record-to-record variability. For a given level of confidence, it is desirable to find an efficient method which can reduce the variability in the results with the use of fewer records.

This paper proposes a method for dispersion reduction of nonlinear seismic response which results to a more reliable loss estimation. The method has been tested on a 3 stories infilled reinforced concrete structure for which the experimental results are available for comparative studies. The results of a comprehensive statistical study of aleatory uncertainty distribution in Structural response are presented. These uncertainties are computed for different levels of strong motions which represent seismic characteristics of a predefined scenario. The study is based on two categories of time histories recorded on near-field and far-field regions. Inelastic displacement ratios associated with mean values are presented and special emphasis is given to the dispersion of responses. Dispersion of responses in each group are monitored with emphasizing on "scaling parameters", "changes in natural period of vibration" and "level of ground shaking"

## SEISMIC RESPONSE OF ROTUNDA MONUMENT DUE TO THE THESSALONIKI 1978 EARTHQUAKE – ID 418

*I. Doudoumis, Aristotle University of Thessaloniki, Greece*
*M. Kallioudakis, Aristotle University of Thessaloniki, Greece*

The Rotunda of Thessaloniki, built in about 300 years A.D., is one of the most important domed monuments in the Balkan region. The main building includes (a) the initial structure of the Roman period, and (b) an addendum building in extension, that was built about 100 years later. The present paper concerns the initial building of the Roman period. It's about a massive masonry building, which has a circular shape in ground plan and a cylindrical form in its lower part, covered with a hemispheric dome. From its first construction (Roman shape) until today, the building's load-bearing system has undergone repeated structural adaptations. The most important took place at the 9th century A.D. (Byzantine shape), when the exterior cylindrical wall was cut at the eastern side. Recently, an refined analytical structural modelling has been attempted for this monument by using solid finite elements and an inelastic static analysis has been performed for gravity loads. Namely, 8 alternative models were formed, corresponding to the 2 different structural systems of the Roman and Byzantine shape respectively, together with 4 variants of the ine-lastic constitutive law that describes the behaviour of the masonry. In this paper the seismic response of these models is studied, due to the Thessaloniki 1978 earthquake (M=6,5R), which caused serious damage in the monument. In particular, a dynamic non-linear time-history analysis is carried out for the simultaneous action of the 3 acceleration components of this earthquake. Among the various results of the analysis, char-acteristic plots are presented, which indicate the stress distribution and the damage zones developed within the models during this earthquake. In conclusion, the Roman shape of the building offered considerably higher strength capacity than the Byzantine one, and this strength capacity definitely depends on the details of the strength models which are adopted for the masonry.

## INVESTIGATION OF THE BEHAVIOR OF CONCRETE TALL BUILDING WITH STAGGERED SHEAR WALL – ID 419

*S. Amiri, Tabriz University, Iran (Islamic Republic Of)*
*M. Yousefzadh, Tabriz University, Iran (Islamic Republic Of)*
*A. Davaran, Tabriz University, Iran (Islamic Republic Of)*
*A. Kashefi, Tabriz university, Iran (Islamic Republic Of)*

The use of continuous shear wall in the height of building is structurally very useful. However in some buildings, the continuous shear walls lead to some difficulties, such as architectural limitations and huge foundation for shear walls. To overcome the problems, an alternative solution is the use of staggered shear walls. However in the structures with staggered shear walls, since the walls are not located over each other in the consecutive stories, the horizontal shear due to lateral loads is transmitted to the lower stories through the floor diaphragm. Therefore, the rigidity of the floor diaphragm is of a great importance. In the current study, to investigate the effect of the diaphragm is of a great importance. In the current study, to investigate the effect of the rigidity of the floor diaphragm on the load-carrying procedure of the structures with staggered shear walls, different parameters are considered, i.e. the number of stories, the ratio of length to width of the plan, the thickness of walls and diaphragms and distance of walls to each other. Furthermore, the study was carried out for both rectangular and I-shape plans. Finally, the behavior of aforementioned structures and comparison of the frequencies, the maximum lateral displacements and the shear in the walls and columns as the response of rigid and flexible diaphragms were highlighted and outlined.

## A COMPARATIVE STUDY ON STATIC PUSH-OVER AND TIME-HISTORY ANALYSIS METHODS IN BASE ISOLATED BUILDINGS – ID 420

*N. Doudoumis, Aristotle University of Thessaloniki, Greece*
*C. Kotanidis, Aristotle University of Thessaloniki, Greece*
*I. Doudoumis, Aristotle University of Thessaloniki, Greece*

For the analysis and design of seismic isolated buildings with an expected inelastic behaviour of the superstructure, two analysis methods are generally acceptable today by the Code Provisions: • The dynamic non-linear time history analysis, that is permitted for all structures and • The static push-over analysis which can be applied to a broad category of buildings that meet certain requirements. The main purpose in the use of this method is to significantly re-duce the computational effort without at the same time reducing the credibility of the results. In the current paper, a specific case study is presented, where the two above mentioned methods are used for the calculation of the response of a multi-storey concrete building with a base isolation system. The purpose of the paper is to clarify certain details which are essential for the application of these two methods, to study the differentiation in their results and furthermore to correlate the conclusions acquired from them with the related references of the FEMA 356, FEMA 450 and Eurocode 8 Provisions. In the examined multi-storey building, two different base isolation systems

are successively applied, together with a respective modification of the superstructure's strength capacity, so that in the first system (model1) the application of the static push-over method is allowed by the regulations (FEMA 356), while in the second system (model2) this application is not allowed. After-wards the two models are analyzed by using the dynamic non-linear time history method, as well as the static push-over method, and their response results are evaluated and compared. The first obtained results seem to confirm the Code' Provisions in general, however there are still several open issues that must be further studied.

### INFLUENCE OF GROUND MOTION DURATION ON DEGRADING SDOF SYSTEMS – ID 425

*E. Bojórquez, Institute of Engineering, University of Mexico, Mexico*

There are many efforts trying to understand strong motion duration effects on seismic response of structures. It has been shown to some extent that, displacement based demand measures are independent on duration conditionally to spectral acceleration, at least for non-degrading hysteretic models. The aim of the paper is investigating the role of ground motion duration for degrading nonlinear single degree of freedom (SDOF) systems in terms of different indexes representing maximum and cumulative demands. Constitutive laws of SDOF systems were obtained using a modified bilinear behavior trough two different degradation functions, the first given by hysteretic energy and the second by maximum displacement. Strength and stiffness degradation are included. All the study cases have been subjected to nonlinear dynamic analysis using selected accelerogram sets representing short and long duration scenarios. For considered demands, statistical hypothesis test and incremental dynamic analyses, as function of ground motion intensity, were used as preliminary step to assess the influence of strong motion duration. Furthermore, fragility curves were considered to evaluate impact of duration on seismic response and reliability of SDOF systems at different capacity levels. The results presented lead to the conclusion that duration content of ground motion depends on the hysteretic model considered and period of the structures.

### INELASTIC ABSORPTION ENERGY FACTORS FOR SHORT PERIOD DETERIORATING SDOF SYSTEMS – ID 429

*L. Ibarra, SwRI, United States*
*Y. Kim, U.S, NRC, United States*
*A. Chowdhury, SwRI, United States*

Probabilistic risk assessment methodologies have been largely utilized in the nuclear industry to evaluate the seismic margin of structural systems. In methodologies such as the high confidence of low probability of failure (HCLPF), the seismic margin is expressed in terms of the earthquake intensity that compromises the structural safety. Among other factors, this seismic margin accounts for the inelastic energy absorption capabilities of the structural components. Because the seismic margin is associated to different levels of damage, the inelastic strength capacity needs to be correlated with deformation parameters. Structural components of nuclear facilities that withstand lateral loads usually consist of very thick reinforced concrete shear walls with low aspect ratios, resulting in systems with a short fundamental period of vibration and deteriorating nonlinear characteristics, which may lead to brittle failure. In this study, parametric studies are performed to estimate the inelastic absorption energy capability of short period deteriorating single-degree-of-freedom (SDOF) systems with low-ductile nonlinear characteristics. Several factors that contribute to an increase in the uncertainty of the response are evaluated, such as record-to-record variability, and uncertainty of some of the parameters defining the nonlinear behavior of the system. The resulting statistical response allows generation of fragility curves that can be used, for instance, for the computation of the HCLPF capacity of generic systems.

The results indicate that inelastic absorption energy factors largely depend on the displacement at the peak strength of the backbone curve of the hysteresis loops because of the steep slope of the softening branch of the evaluated systems.

Disclaimer: This abstract is an independent product of the authors and does not necessarily reflect the view or regulatory position of the NRC. The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed.

### STUDY ON STIFFNESS FACTOR BASED ON EARTHQUAKE RESPONSE CHARACTERISTICS OF WOODEN-FRAMED HOUSES – ID 434

*A. Yamada, Hirata Structural Engineers Inc., Japan*
*S. Suzuki, Kansai University, Japan*
*K. Asano, Kansai University, Japan*

The "Wall Quantity" using in design procedure for wooden–frame houses is also one of the most important key points for the earthquake damage prediction. It is common that the earthquake damage levels of houses depend on the wall quantity and those houses have been designing under the Building Standard Law in Japan. The behaviors of earthquake resistant and non-resistant walls are qualitatively recognized but are not made clearly in quantitative. In particular, the dynamic behaviors are not understood in detail. It is necessary to know that the non-resistant walls play an important role and parameter during earthquakes. In this paper, we discuss the influence of the resistant and non-resistant walls on the earthquake responses from the dynamical view point in order to clarify the relationship between the stiffness of wall and the total stiffness of a house. The two typical restoring-force models are introduced to the analytical wooden models: i.e. the stable hysteretic and slip ones. The combination between the two restoring force models is divided in the ratio 2 : 3, respectively. "Stiffness Factor" is defined on the basis of the secant stiffness at the 1/120 radian deformation in the restoring force model, and introduced to the analysis. Selecting 4 to 6 for the Stiffness Factor, almost maximum displacement responses during earthquakes would quite agree with the damage levels. This factor corresponds to the seismic design philosophy that the walls of wooden houses will resist against small to strong earthquakes. It is expected that this "Stiffness Factor" presented herein will be extended to all wooden houses in the world, which have lots of different kinds of walls and other seismic elements.

### SEISMIC ANALYSIS OF BRESINA ARCH-GRAVITY DAMS USING COMPLETE STOCHASTIC DEAMPLIFICATION APPROACH – ID 440

*N. Meddane, Assistant professor, Algeria*
*M. Djafour, Assistant professor, Algeria*
*R. Derbal, Doctoral Research Assistant, Algeria*
*A. Megnounif, Assistant professor, Algeria*
*D. Zendagui, Assistant professor, Algeria*
*A. Bekkouche, Associate Professor, Algeria*

The dynamic response of the Brézina gravity arch dam, in western Algeria, to spatially varying earthquake ground motion is investigated in this paper. The deterministic displacement time-histories used as input ground motions were obtained through simulation based on the complete stochastic deamplification approch. Both incoherence and wave passage effect are taken into account. An undamped 3D finite-element model is used to represent the dam and a time history analysis is performed. For this stiff structure, the results indicate that the spatial variability of ground motion can produce stresses greater than those due to identical excitation. By decomposing the stress response into pseudostatic and dynamic parts, it has been shown that pseudo-static stresses are very important in the vicinity of the base of the dam. These stresses decrease far from the base. For the dynamic components, the response due to uniform load and taking account the spatial variability of ground motion are of same order.

### EVALUATION OF LOAD PATH EFFECT IN PUSHOVER ANALYSIS OF FRAMES – ID 446

*A. Yakut, METU, Turkey*
*S. Oguz, METU, Turkey*

Pushover analysis procedure has been widely used in performance-based assessment of structures. The accuracy of pushover analysis depends strongly on the shape of the height wise distribution of lateral loads applied. Research has been carried out to evaluate the influence of common lateral load patterns on the results of pushover analysis of frames. A number of low, mid and high rise reinforced concrete and steel frames have been analyzed under several ground motions that have been scaled such that the structures deformed into varying levels of inelasticity. This way, unlike previous research, the accuracy of pushover procedures was evaluated at elastic as well as varying inelastic response levels. Aside from global pushover curves, interstory drift ratio profiles, story displacement profiles, story capacity curves and hinge patterns obtained from pushover analyses have been compared with the results obtained from nonlinear time history analyses. The investigations revealed that accuracy of pushover procedures depend strongly on the load path, the structural system and the characteristics of the ground motion. The ability of the pushover procedures to capture the global behavior was observed to be much better than representing the plastic hinge patterns obtained from nonlinear analyses. The variation in the global pushover curve with respect to the load path was relatively small as compared to the interstory drift ratio and displacement profiles. In general, the ability of pushover procedures to simulate the height-wise deformation profiles were observed to be better in the elastic response range of the frames, but significant discrepancies were observed in the inelastic deformation levels. The degree of accuracy decreased as the height of frame increased. Guidelines are provided for the selection of most feasible load pattern in the analyses of frame structures.

## DUCTILITY DEMANDS OF BUILDING STRUCTURES SUBJECTED TO GROUND MOTIONS REPRESENTING DESIGN EARTHQUAKE – ID 453

*D. Ladjinovic, University of Novi Sad, Faculty of Technical Scien, Yugoslavia*
*R. Folic, University of Novi Sad, Faculty of Technical Scien, Yugoslavia*

Building structures have adequate earthquake resistance if their supply limit capacity exceeds, within certain margin of safety, seismic demands in the case of severe earthquakes. For the rational aseismic design of building structures, a procedure is needed which would yield an adequate estimation of seismic demand in terms of structural stiffness, strength, ductility and energy dissipation. The paper presents the use of energy parameters in the evaluation of seismic performance of structural systems. The simplified method for design of earthquake resistant structures that includes cumulative damage effects is presented.The improved damage index, based on plastic deformation and hysteretic energy dissipation, is proposed. The proposed damage index is presented in generalized form, in the function of maximal amplitudes of plastic deformations, available ductility capacity and function including cumulative damage effects due to the dissipation of hysteretic energy. This function, besides the parameter including influence of deterioration, depends on achieved plastic deformations during earthquake and normalized hysteretic energy, and on cyclic and accumulated ductility. By introducing this function it is possible to include not only the structural properties, but also the characteristics of the earthquake and the effects of the duration of strong ground motions.The influence of several structural parameters (initial structural period, strength capacity, target ductility, hysteretic behaviour), as well the characteristics of ground motion, on structural response and level of damage are quantified and presented. Deformation demands of structures designed according to Eurocode 8 have been obtained through statistical studies of the seismic behaviour obtained by the non-linear analysis of SDOF system subjected to time-histories representing design earthquake. Through the paper it is shown that on ductility demands the significant influence have not only the intensity and type of seismic action, but also the structure's stiffness, yield strength and the allowed damage degree.

## DECOMPOSITION OF THE STIFFNESS MATRIX TO STUDY THE DYNAMIC BEHAVIOR OF MDOF STRUCTURES USING SPRING- – ID 465

*S. De La Cruz, Universidad Autónoma de Ciudad Juárez, Mexico*
*F. López-Almansa, Universitat Politècnica de Catalunya, Spain*

This paper presents a procedure to decompose the stiffness matrix of structures as an option to analyze the dynamic behavior of building structures in which the flexural rigidities of the beams, in addition to those of the columns, are considered. The recent development of commercial software intended to solve the equations of motion of single-degree-of-freedom (SDOF) and multi-degree-of-freedom (MDOF) structures, has facilitated the analysis of the dynamic behavior —linear and non-linear— of 2D and 3D beam-column models, especially when dealing with structures equipped with some kind of energy dissipation devices. On the other hand, SDOF and MDOF building structures, typically represented by spring-mass models, can be analyzed by writing and solving the equations of motion that include inertial, damping, stiffness and external forces. However, since the stiffness forces are idealized by means of linear (or nonlinear) springs, such an idealization is usually limited to structures that behave as shear-buildings. In other words, when analyzing a moment resistant frame (MRF), it is necessary to write the stiffness matrix considering the flexural stiffness of the beams located at each floor. This procedure leads to a stiffness matrix whose order is bigger than the number of floors. Therefore, a static matrix condensation procedure is required to reduce the order of the stiffness matrix. The procedure presented here consists in manipulating the condensed stiffness matrix as to the spring-mass models still be adequate to work with, when using a commercial software such as ANSYS or ADINA. The latter is used for the numerical simulations. Results are given for MRFs of two and three floors. The comparisons show the 'equivalence' between the spring-mass models and the more elaborated beam-column models. For building structures with more than three floors, this same procedure can also be applied.

## UPLIFTING ANALYSIS OF UNANCHORED STEEL STORAGE TANKS UNDER HORIZONTAL COMPONENT OF EARTHQUAKE – ID 475

*S. Eshghi, IIEES, Iran (Islamic Republic Of)*
*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*
*M. N. Ahari, IIEES, Iran (Islamic Republic Of)*

Local uplift of the tank wall is probably the most important characteristic of the seismic behavior of unanchored liquid storage steel tanks. For the uplift analysis of the tanks, rigid body dynamic method, which neglects the resisting action of the base plate, has been used. In another approach tank wall and liquid content are modeled with a mass-spring system, and the nonlinearity associated with the partial uplift of bottom plate is considered as the rotational spring system or circumferential translational springs. In this method, moment of inertia of liquid for rocking motion is neglected. In this paper the uplifting behavior of unanchored tanks is discussed through introduction of rigid bodies dynamic. Tank wall and portion of the liquid residing on uplifted floor section are modeled as a rigid body and resisting action of base plate modeled with equivalent nonlinear circumferential springs. Finally, the critical responses of representative tanks are evaluated for increasing intensities of an earthquake ground motion, and the effects and relative importance of the problem parameters are highlighted. The studies shows that proposed model can effectively represent the seismic behavior of unanchored tanks especially with regard to uplift.

## ANALYTICAL INVESTIGATION OF MASSIVE WOODEN WALL PANEL SYSTEMS SUBJECTED TO SEISMIC EXCITATION – ID 489

*V. Hristovski, IZIIS, Macedonia*
*M. Stojmanovska, IZIIS, Macedonia*

*R. Zarnic, ULFGG, Slovenia*
*B. Dujic, ULFGG, Slovenia*

Generally wood-frame systems are attributed to perform well when subjected to seismic action as they have low seismic mass and flex more than other materials, absorbing and dissipating energy. As a result they are often designed without paying enough attention to their seismic resistance and proper understanding of their structural response. Therefore experimental studies are required to quantify static and dynamic characteristics of wood-frame systems and to develop numerical models to simulate their behavior under dynamic loadings.

In the scope of the bilateral Slovenian-Macedonian project titled "Experimental and Numerical Research of Racking Strength of Massive Wooden Wall Panels" supported by the governments from both countries two full-scale models have been assembled and tested on the shaking table at the IZIIS Laboratory, Skopje, Macedonia. The first test specimen consisted of KLH one unit wall elements while the second specimen consisted of KLH two unit wall elements. KLH panels are product of Austrian Company Massiveholz GmbH and represent cross laminated timber consisted of strips of spruce stacked on top of each other and glued together forming large-sized solid cross-laminated boards.

Using SAP 2000 Program a finite element based model for prediction of wood shear wall behavior has been developed and verified against test records. Special attention has been paid to modeling of the connections and simulating different boundary conditions. First Eigen analyses have been run in order to simulate ambient and force vibration tests. Records resulted from the carried out ambient and forced vibration tests have verified the values of stiffness parameters used for the connections, which were previously collected by basic quasi-static tests. Dynamic nonlinear analyses have also been completed applying same earthquake records used in the shaking table test.

Obtained results have shown good correlation between the finite element model and the experimental data.

## EFFECT OF SOIL-STRUCTURE INTERACTION ON SYSTEM DUCTILITY OF STACK-LIKE STRUCTURES – ID 540

*A. M. Halabian, Isfahan University of Technology, Iran (Islamic Republic Of)*
*S. Kabiri, Isfahan University of Technology, Iran (Islamic Republic Of)*

A method is presented to quantify the effect of soil structure interaction on ductility capacity factors of stack-like structures. The deformed configuration of stack like structures is idealized as an assemblage of beam elements, while a linear sway-rocking model is implemented to model the supporting soil. The effect of non-linear behavior of these types of structures including concrete cracking and reinforcement yielding on the stiffness is taken into account using a non-linear moment-curvature (M-Phi) relation. Using a set of artificial earthquake records, repeated linear and non-linear analyses were performed by gradually increasing the intensity of acceleration time histories to a level, where first yielding of steel in linear and non-linear analysis and collapse of the stack in non-linear analysis is observed. The set of time histories thus obtained are then used to define the elastic and ultimate intensity of ground motion that the stack can sustain in each analysis. The difference between inelastic and elastic resistance in terms of displacement ductility capacity factors has been quantified. The results showed that the foundation flexibility could decrease the ductility of the system and neglecting this phenomenon may lead to erroneous conclusions in the prediction of seismic performance of flexibly-supported R/C stack-like structures.

## AN ANALYTICAL INVESTIGATION OF THE RIGID END ZONE FACTOR FOR COUPLED SHEAR WALLS – ID 551

*S. B. Yuksel, Selcuk University, Turkey*

The wide-column-frame analogy was used since 1964 for the analysis of coupled shear walls. Wide-column-frame analogy is also commonly known as the equivalent frame method. The basic assumption of equivalent frame method is to treat walls and beams as discrete frame members. Finite width of the walls is taken into account by placing horizontal rigid arms incorporated in the beam elements. On the other hand, it is not realistic to assume that the behavior of these regions is fully rigid all the way to the wall edge. Especially in squat shear walls, it should be noted that the plane sections of the walls do not remain plane after the deformation of the walls. Accordingly, results for coupled shear walls may be approximate depending on deviation in linear variation of strain distribution of the walls. Also, in equivalent frame method, the effect of local deformations at beam-wall joints is not taken into consideration. Finite element analyses results can be accepted as the real elastic analysis values. The approximate results of the analyses obtained from equivalent frame method are due to neglecting local deformations at beam-wall junctions and idealizing coupled shear walls as a frame composed of two wide columns connected by means of infinitely rigid extension. It is uncertain and not easy to decide how much of the finite width of the shear walls from its centerline to the wall edge has to be considered as rigid for the analyses purposes. In order to gain some insight on this subject, an extensive parametric study is conducted. The Coupled shear walls subjected to triangular distributed lateral load are analyzed both finite element method and equivalent frame method. In equivalent frame method different rigid end-zone assumptions are considered for each model. Results obtained from finite element analysis and equivalent frame method are compared.

## SEISMIC RESPONSE ANALYSIS OF STRUCTURES – ID 597

*A. Kalandarov, KSUCTA, Kyrgyzstan*
*A. Abdykalykov, KSUCTA, Kyrgyzstan*
*B. Mekenbaev, KSUCTA, Kyrgyzstan*
*L. Soldatova, KSUCTA, Kyrgyzstan*

In this paper given analytical and experimental investigations of one and two mass models of a building isolated with sliding bearings. Experimental tests were conducted on a shake table for a harmonic vibration, laboratory of the Kyrgyz State University of Construction, Transportation and Architecture (KSUCTA). One mass model was considered to investigate the working process of sliding bearing and to determine the elastic parameters of control mechanism (restoring force) to limit displacement and prevent the building from sliding off the bearing surface. In this case the building is accepted as absolutely rigid body. As a control mechanism springs and rubber shock-absorbers have been considered. It is established that the amplitude and speed of vibrations of a building depends only on frequency of the foundation and coefficient of friction, and also they decrease with increase in frequency of vibration. Efficiency of a sliding bearing increases with increase in amplitude and frequency of vibration of a surface of the ground. For investigation of influence of stiffness and damping coefficients the two-mass model of a building is considered. In this case the masses of a building were installed on frames of the top belt of the foundation and the top part of a frame. It is established that the amplitude of displacement and acceleration of the foundation due to the characteristic of a building increases. At the established sliding, amplitudes of displacement of the foundation of the top frame of a structure of a building, depends only on its stiffness coefficient. Theoretical and experimental investigations have shown that a deformation of superstructure, maximal accelerations and elastic reactions decreases in several times with increase in seismic influence.

KEY WORDS: seismic isolation, seismic response, sliding isolations, friction bearings

## NUMERICAL ANALYSES OF A SUPPORT SYSTEM FOR PRE-CAST CONCRETE PANELS – ID 612

*G. Metelli, University of Brescia, Italy*
*P. Riva, University of Bergamo, Italy*

Although several works have been focused on the seismic behaviour of RC frames with masonry infills, the dynamic and non linear behaviour of pre-cast structures under seismic actions, with pre-fabricated RC panels used as curtain walls, is still not well known, due to the lack of studies on the interaction of the RC frame and the external pre-cast concrete panels. In common design practice, the bracing effect of the panels on the seismic response of the building is ignored. However, this assumption might be in some cases unsafe or uneconomical in the design of the RC columns of a seismic resisting frames. One of the problems related to precast RC panels, is that the behaviour of the supporting systems under earthquake actions is not well known, both with respect to their strength and ductility. This paper aims to present finite element analyses (FEA) of a particular steel support system used to connect pre-cast concrete panels to concrete structures. The non linear analyses are conducted with FE program DIANA. A three dimensional model has been carried out with tetrahedral elements. The non linear behaviour of the materials and of the contact surface between the panel and the support system are considered. A rotating smeared crack approach has been used to model the concrete cracking zone around the anchors of the support system. The numerical results show a good performance of the support system, both in term of resistance and ductility, so that under seismic actions the pre-cast panel might be act as stiffening and bracing elements in a RC frame.

## DRIFT DEMAND OF FRAME STRUCTURES SUBJECTED TO VRANCEA EARTHQUAKE GROUND MOTIONS – ID 620

*E. F. Albota, TUCE, Romania*
*S. Demetriu, TUCE, Romania*
*R. G. Enache, TUCE, Romania*

In this paper an estimation method for obtaining the maximum inter-story drift ratio (MIDR) and roof drift ratio (RDR) for general frame type structures is presented. Using drift spectra good results are obtained only for pure shear frame systems. This method extends the applicability of drift spectra for general frame structures. Based on modal analysis, this method was developed only for frame structures vibrating predominantly in the first mode. Computational relations are relatively simple and capable to evaluate with enough accuracy drift ratios values. Earthquake ground motions used in this study were recorded in different site conditions in Bucharest during the last three major 1977, 1986 and 1990 Vrancea earthquakes. The generic multi-story frame structures used in analysis were developed having some particular characteristics. MIDR and RDR are expressed as a function of the beam-to-column stiffness ratio ($\rho$) and spectral displacements (SD). Results obtained using presented method are compared with these resulted from a linear dynamic time-history type analysis. Finally, MIDR/RDR and RDR/(SD/H) ratios are analyzed as a function of different parameters. The MIDR/RDR ratio becomes bigger with increased values of beam-to-column stiffness ratio $\rho$, fundamental period T1 and PSA(T2)/PSA(T1) ratio. RDR/(SD/H) ratio has almost a constant value of 1.27 for a large range of common periods of vibration and for all the $\rho$ parameter values.

## NON-LINEAR DYNAMIC RESPONSE ANALYSIS ON MULTI-STORY FRAMES WITH SIMPLIFIED HEXAGONAL FAILURE SURFACE – ID 640

*J. H. Choi, Kobe university, Japan*
*K. Ohi, Kobe university, Japan*

The emphasis in seismic resistance design is shifting from "strength" to "performance" following the demand and collapse of numerous structures during recent earthquake. Gradually, performance based designs are becoming a part of code provisions with publication of FEMA-273 in USA and Enforcement Order and Regulation after Building Standard Law of Japan was revised in 1998. At the same time, it may be fair to say that simple and efficient methods for capturing the essential and important features affecting the performance have not been adequately developed. The objective of this paper is to develop a design friendly method for performance evaluation of ductile steel moment-resisting frames, which are used as the primary lateral load resisting systems in many middle-rise buildings. Proposed research focuses on the simplifications of non-linear dynamic design procedures (NDP). This paper presents a non-linear dynamic procedure with partial-mode response analysis with simplified plastic failure surface models. A safety domain about plastic collapse of an elastic-perfectly plastic frame is approximated by a yield polyhedron with a reduced number of failure modes. To reduce the number of failure modes, a preliminary analysis based on first-order second-moment (FOSM) reliability method is proposed. This method requires, however, an exhaustive procedure to enumerate the whole failure mechanisms, and the failure surface becomes a convex polyhedron made of a lot of hyper surfaces even after they are reduced. Sometimes it happens to encounter the problem of dealing with extreme points during the renewal procedure of restoring force. To avoid them, an alternative method is proposed in this paper. The plastic failure surface is approximated by a hyper-ellipsoidal model, which has no extreme point and provides a much easier procedure to trace the inelastic global behavior than the yield polyhedron model.

## ROTATIONAL DUCTILITY DEMAND EVALUATION OF COUPLING BEAMS BY MONTE CARLO SIMULATION – ID 668

*M. A. Shayanfar, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*P. Esmaili, Iran University of Science and Technology, Iran (Islamic Republic Of)*

Coupled structural walls provide great strength and adequate lateral stiffness especially for high rise buildings. There are three main modes of failure for coupled structural walls: failure of coupling beams in flexure, failure of coupling beams in shear (diagonal splitting), failure of walls (rigid action of coupling beams). Regarding to failure modes and elastic-plastic analysis of coupled structural walls, a program is written using MATLAB to examine behavior of the coupled walls over the entire load history and determine their lateral load capacity. However, coupled structural walls reach to their ultimate capacity, if the coupling beams provide adequate ductility. Therefore, determination of the coupling beams ductility demand is also considered in this program. Since the variables involved in analysis and design of structures are probabilistic in nature(not deterministic), some changes are applied to the program using the Monte Carlo simulation technique to evaluate ductility demand and lateral load capacity of coupled walls with a pre-defined confidence level. Several coupled walls with different sections and different heights of coupling beams are analyzed and their rotational ductility demands are evaluated.

Keywords: coupled structural walls, ductility demand, Monte Carlo simulation, elastic-plastic analysis

## RELATIONSHIP OF SEISMIC RESPONSES AND STRENGTH INDEXES OF GROUND MOTIONS FOR A LARGE-SCALE RIGID STRUCTURES – ID 718

*S. O. Citak, Kyushu University, Japan*
*H. Kawase, Kyushu University, Japan*
*M. Fushimi, Japan Atomic Power Company, Japan*
*S. Ikutama, Japan Atomic Power Company, Japan*

This study focuses on seismic response of large-scale rigid structures such as a nuclear power plant (hereinafter LSR structures) as a function of seismic parameters of strong motions. Seismic parameters are represented by strength indexes of ground motions such as PGA, PGV, A0 (the measurement parameter for JMA seismic intensity), and PGA*PGV, while structure response are represented by shear force at each floor. The main objective of the study is to investigate the relationship of seismic responses of LSR structures and strength indexes of ground motions or ground motion parameters and to identify basic shear indexes that can indicate or predict the damage level that we have to expect in future without complex calculations. For this purposes first the basic dynamic characteristic of typical LSR structures, namely, modes, natural frequencies, and transfer functions were

calculated. Second, strong motion records were selected from various sites and earthquakes and used as an input motion for Nonlinear Direct Integration Time History Analysis of these LSR structures. Finally, shear force response of linear members were correlated with strength indexes of ground motions in order to obtain shear indexes. The computer code SAP2000, one of the most widely used static and dynamic Finite Element Analysis code, is used for Direct Integration Nonlinear Time History Analysis. The relationship between seismic responses of a large-scale rigid structures and strength index of ground motions were investigated. We found that the regression lines, especially with PGA for upper floors and A0 for lower floors, can be used for the easy assessment of seismic response and could be the basic indexes for the prediction of damage level of LSR structures without complex calculations.

## DAMAGE OF REINFORCED CONCRETE STRUCTURE UNDER EXTREMELY STRONG GROUND MOTION – ID 771

*M. Saisho, Kumamoto University, Japan*
*D. Hayamichi, Kumamoto University, Japan*

The collapse of building structure and the injury to person have been observed in the recent severe earthquakes. In order to prevent these building collapses, the damage of the multi-story reinforced concrete structure (RC structure) under extremely strong ground motion is investigated.

Seismic response collapse of RC-frame is closely related to the failure of column. According to our test results, the failure of RC-column is caused from the steel bar fracture of it. The steel bar fracture of RC-column is also observed in the recent severe earthquake disasters. From these reasons, the failure conditions of RC-column defined by the steel bar fracture are obtained and applied to the numerical analysis of RC-frame collapse under extremely strong earthquake motion. In this analysis, the steel bar fracture is assumed to be the very-low cycle fatigue behavior and the fracture condition of it is obtained on the basis of the Manson-Coffin Equation and the Palmgren-Miner Rule.

In addition to the fracture conditions, the restoring force of RC-column expressed by the Tri-linear model and the modified Clough model is introduced to carry out the numerical analysis of the seismic response collapse and the damage ratio of RC-frame. Based on the calculations, the seismic response damage of RC-frame is investigated in relation with the design conditions of RC-frame.

## DAMAGE OF CONCRETE FILLED STEEL TUBE STRUCTURE UNDER EXTREMELY STRONG GROUND MOTION – ID 775

*M. Saisho, Kumamoto University, Japan*
*M. Kato, Aichi Sangyo University, Japan*

The basic object of earthquake resistant design of building structure is to prevent the seismic response collapse and the injury to person which have been observed in the recent severe earthquake disasters. In order to prevent the seismic response collapse, the damage ratio based on the collapse behavior of building structure need to be analyzed.

In this study, the damage of the concrete filled steel tube frame (CFT-frame) under extremely strong ground motion is investigated. By the use of the non-dimensional restoring force model of CFT-column which is expressed by the Tri-linear model and the modified Clough model and by introducing the local buckling condition and the crack condition of steel tube, the numerical analysis method to calculate the collapse of CFT-frame has been obtained. The obtained collapse analysis method can calculate the damage ratios of the local buckling and the crack of steel tube of CFT-column which are closely related to the collapse of CFT-frame under seismic load.

The damage ratios of CFT-frame in the seismic response and the collapse behavior are also investigated in relation with the design conditions of frame. It is ascertained that the local buckling and the crack of steel tube of CFT-column are closely related to the dynamic collapse of CFT-frame and they are the basic design factors of CFT-frame against extremely strong ground motion.

## INVESTIGATION OF SHEAR AND FLEXURAL RESPONSE OF BUILDINGS TO PULSE-LIKE GROUND MOTIONS IN NEAR-FIELD – ID 779

*A. R. Khaloo, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. Khosravi, Sharif University of Technology, Iran (Islamic Republic Of)*

This paper presents an investigation of multimode effect of tall buildings idealized as a continuous beam model influenced by near-field pulse-like motion. Since the lateral deformations in the buildings are usually a combination of shear-type deformations and flexural-type deformations, a combination of a flexural cantilever beam and a shear cantilever beam is considered as an appropriate model. The model is subjected to near-field ground motions and the representative simplified pulses and the maximum interstory drift along the height is calculated. The computation is based on the modal summation approach and in order to study a wide range of engineering structures, maximum drift and its height spectra are drawn. Multi-mode response of beam is compared to the first mode response and an acceptable range of first mode estimation is found. The results indicate that simplified pulses represent near fault records well and the shear deformation to flexural deformation ratio, the ratio of fundamental structural period to the predominant pulse period and the velocity pulse shape control the quantity of interstory drift and its location along the building height. In the end, a set of simple Green's function for different height of the beam is derived that not only explains many response characteristics of different beams but also predicts the height of maximum drift.

Keywords: Near-Field earthquakes; Pulse-like ground motions; Buildings; Interstory drift; Beam model; Shear-type and flexural-type deformations; Green's function.

Contact: khaloo@sharif.edu

## EFFECT OF TRANSFER SLAB ON THE DYNAMIC RESPONSE OF HIGH-RISE REINFORCED CONCRETE BUILDING – ID 815

*J. A. Abdalla, American University of Sharjah, United Arab Emirates*

The use of transfer slabs in reinforced concrete buildings has increased in recent years to provide open space in the floor beneath for different functions. Transfer slabs that carry columns of 10 to 15 stories are very common. These transfer slabs are usually designed to carry very large concentrated loads coming from the columns above. Such large concentrated loads require very high punching shear capacity. Accordingly, the thickness of a typical transfer slab is usually several times that of the slab above or below it. As the result, the use of transfer slab in reinforced concrete buildings introduces a very large mass at that floor and therefore large inertia forces will developed when subjected to earthquake excitation. This is usually not accounted for when buildings with transfer slabs were designed based on static analysis only.

This paper presents a study of the effect of transfer slab on the dynamic response of a high-rise reinforced concrete building. A 13 story building with a transfer slab located at its third floor has been used as an example. Linear dynamic analysis of the building with and without the transfer slab is carried out to compare the dynamic characteristics of the two buildings. The two buildings are then analyzed using nonlinear static pushover with different load distribution and their dynamic performance are compared. ATC-40 and FEMA-356 modeling and analysis procedures together with the enhancement introduced in FEMA440 is used. The distribution of the inelastic deformations and plastic hinges are monitored. The effect of the transfer slab on the columns above and below its floor as well as on the dynamic behavior of the whole building is then assessed.

### NUMERICAL SIMULATIONS AND ENGINEERING METHODS FOR EVALUATION OF SEISMIC BEHAVIOUR OF EXPERIMENTALLY TESTED SHEAR WALL – ID 817

*M. Kostov, CLSMEE, Bulgaria*
*D. Stefanov, CLSMEE, Bulgaria*
*N. Koleva, CLSMEE, Bulgaria*

This paper presents the Bulgarian participation in Coordinate Research Program (CRP) on Safety Significance of Near Field Earthquakes (NFE) organized by IAEA. The CRP aims to study to what extent recent developments in analytical methodologies for predicting earthquake response behaviour of nuclear structures can be used for the assessment of nuclear facilities subjected to NFE earthquake ground motions. In the CRP, the experiment data obtained by the Commissariat a l'Energie Atomique (CEA) Saclay Research Laboratory in France is taken up for a benchmark analysis. Several analyses are performed – static analysis, spectral analysis, displacement based approach and time history analysis. Comparative calculations for the investigated structures are done. Two records, representing far and near field earthquakes, are modified 6 times, scaling the PGA from 0.1g to 0.6g. Except for the conventional parameters of the seismic response like accelerations, displacements, acceleration response spectra, two more quantities - damage index and cumulative absolute velocity (CAV) are calculated. Relation between the two last parameters as well as between the maximum acceleration and CAV are derived respectively for far and near field earthquakes. Comments and discussion about the damage potential of near field earthquakes are presented.

### DEFORMATION CAPACITY OF R.C. ELEMENTS WITH SUBSTANDARD DETAILS – ID 842

*D. Syntzirma, Demokritus University of Thrace, Greece*
*S. Pantazopoulou, Demokritus University of Thrace, Greece*

The inventory of structures that would be classified as old or substandard construction with reference to modern seismic design standards is vast throughout the world. For this reason development of methods for seismic assessment of such structures is a great and pressing priority for the earthquake engineering community. The one aspect of performance most affected by the lack of proper detailing, which is a typical characteristic of old or substandard construction is the limited deformation capacity of the structural members and of the structural system as a whole. However, estimating deformation capacity of R.C. elements is hampered by the complexity of the associated mechanics problem, the observed scatter from experimental results and the limited understanding of the effects of load history on the interacting strength mechanisms. In poorly detailed members deformation capacity seems to depend on localization in the prevailing mode of failure. To identify the controlling mode and the deformation capacity at the onset of localization in the response an index of failure potential is established for each possible failure mode. The predictive capability of the proposed procedure is also explored experimentally, through a series of component tests that comprise sixteen specimens modelling R.C. columns with substandard details representative of former construction practices. Columns are cantilevers with a square cross section and lap–splices in the critical region. Detailing of the specimens was done so as to develop closely interacting modes of failure because identifying apriori the prevailing mode of failure and the associated deformation capacity appears to be the most critical benchmark test of analytical assessment procedures of substandard R.C. elements. Results of the correlation between analysis and experimental values are included in the presentation, and conclusions are drawn with regards capacity–based prioritizing of closely spaced strength mechanisms in reinforced concrete.

### SEISMIC RESPONSE AND BEHAVIOR OF ANCIENT COLUMNS – ID 877

*L. Papaloizou, University of Cyprus, Cyprus*
*P. Polycarpou, University of Cyprus, Cyprus*
*P. Komodromos, University of Cyprus, Cyprus*

The investigation of the seismic behavior of ancient monolithic and multi-drum columns is scientifically interesting, as it involves complex rocking and sliding phenomena of the individual rock blocks. In addition, the understanding of the behavior and response of these structures during strong earthquakes is useful for the assessment of conservation and rehabilitation proposals for such structures.

Considering that analytical study of such multi-block structures under strong earthquake excitations is practically difficult if not impossible, numerical methods can be used to simulate the dynamic behavior and seismic response of these structures. The discrete element method (DEM) is utilized to investigate the response of ancient multi-drum columns during strong earthquakes by simulating the individual rocks blocks as distinct rigid bodies. Although most numerical methods of computational mechanics are based on continuity assumptions, the DEM have been specifically developed for the simulation of systems of multiple independent bodies that can move relatively freely in space while interacting with each other through contact forces.

A software application is specifically developed to perform efficient seismic simulations of multiblock structures in order to investigate and understand the influence of different characteristics of earthquake excitations as well as the various mechanical and geometrical characteristics of these structures on their seismic response. A large number of simulations of columns with varying mechanical and geometric characteristics of drums and columns are performed under the action of various harmonic oscillations and earthquake excitations, gaining an insight into the behavior of these structures during strong earthquakes.

### RESPONSE OF SDOF SYSTEM TO NON-STATIONARY EXCITATION CONSIDERING STOCHASTIC CHARACTERISTICS OF PHASE SPECTRUM – ID 897

*Y. Murono, Railway Technical Research Institute, Japan*
*T. Sato, Waseda university, Japan*

The expectation of a peak value for a stationary random process can be obtained by using the Spectrum Moment Method. The peak response of a structure, therefore, can be derived by using only the Fourier amplitude spectrum of an input earthquake motion and the frequency response function of the structure, if the earthquake motion is a stationary random process. But the earthquake ground motion is obviously a non-stationary process. It is well kwon that a phase characteristic of earthquake motion strongly controls the non-stationary nature of earthquake motions. In this study we use the concept of group delay time, tgr, instead of Fourier phase spectrum, because a modeling the group delay time is much easier than directly modeling of phase spectrum. Tgr spectrum and its standard deviation represent an average arrival time of earthquake energy and a duration of earthquake motion, respectively. The stochastic characteristics of tgr at a certain frequency can be defined to have the Gaussian nature which is defined by its mean value and variance along the frequency. In this study, the methodology to introduce the stochastic characteristics of the group delay time spectrum, tgr, into the random vibration analysis of SDOF system is developed. The close solutions of mean and mean square response of SDOF linear system to the non-stationary excitation are described strictly with mean and variance of tgr. We also propose a methodology to estimate an expectation of response spectrum for a non-stationary random process by using these solutions. The effect of phase spectrum uncertainty on a structural response is investigated.

### OPTIMUM TORSION AXIS AND PRINCIPAL DIRECTIONS IN MULTI-STORY BASE ISOLATED BUILDINGS – ID 929

*A. Athanatopoulou, Aristotle University of Thessaloniki, Greece*
*N. Doudoumis, Aristotle University of Thessaloniki, Greece*

According to modern seismic codes, the definition of the

optimum torsion axis and the principal directions constitutes one of the essential steps for the structural design when simplified methods of analysis are used. This issue has been addressed for the case of multi-story buildings with fixed base and analytical formulae exist that allow the determination of the optimum torsion axis location and the orientation of the horizontal principal directions. In the current paper, the above mentioned analytical procedure is focused on multi-story buildings with a linear base isolation system. Two different multi-story buildings are selected and the location of their optimum torsion axis along with the orientation of the principal directions is determined using the same equations as in the case of fixed base buildings. Next the basic properties of the optimum torsion axis and of the principal directions are verified using static analysis. Furthermore the dynamic behavior of the isolated buildings is investigated for different locations of the optimum torsion axis (i.e. the optimum torsion axis coincides or does not coincide with the vertical mass axis), using a modal and a linear time-history analysis. The produced results verify that when the optimum torsion axis coincides with the vertical mass axis of the superstructure, the building's vibration modes become nearly uncoupled. As a result, the building's displacements along the principal direction where the ground motion has been applied are maximized while the displacements along the perpendicular direction tend to take almost zero values. This is an important conclusion that can be further used for the optimum seismic design of multi-story buildings with base isolation.

### USING OF BOUNDARY EQUATIONS UNDER CALCULATION OF UNDERGROUND STRUCTURES ON SEISMIC EXCITATIONS – ID 948

*J. Nizomov, Earthquake Engineering and Seismology, Tajikistan*

The solution of the tasks related the tensely strain state on the entry contours of the subsurface structures of the Rogunskaya Hydroelectric Power Station using the method of the end integral equations to set out in writing here. The task solution inclusive of work the supporting structures have resulted. In the mechanics of rigid deform bodies the exact and approximate mathematical methods of design the wide class of the tasks related tensely strain state of the simply connected and manifold domains, homogeneous and piecewise-homogeneous domains have got significant evolution. These approximate mathematical methods of design use for description the processes that have in the rock masses, and help to solve the applications, which necessary for the tasks solution of the underground excavations. In connection with advance construction the unique complexes of power, hydro-engineering, transportation and other subsurface structures in the seismic active regions the questions of solidity and reliability of the buried structures under influence of the static and dynamic loads. The solution of the boundary value problem by means of attack it to the solution of the linear integral equation with help of potentials that have got in terms of fundamental solutions is the one of the basic method of research the boundary value problems in the theory of equations with partial derivatives. Investigation the strain concentration on plane that weaken by the aperture with noncircular shape under tectonic and seismic impacts is the complex problem. The effectiveness of the conformal mapping method depend from kind of function, which provide the transformation of the region under consideration on any primary canonical domain (cycle, half-plane and so on), for this reason the solution of the problem with the complex shape apertures significant complicate.

### PORTAL OF DAMAGE: A WEB-BASED FE PROGRAM FOR EARTHQUAKE ENGINEERING APPLICATIONS – ID 964

*M. Uzcategui, University of Los Andes, Venezuela*
*B. Vera, University of Los Andes, Venezuela*
*M. E. Marante, Lisandro Alvarado University, Venezuela*
*J. Redondo, University of Los Andes, Venezuela*
*M. Puglisi, University of Los Andes, Venezuela*
*J. Flórez-López, University of Los Andes, Venezuela*

This paper describes the first web-based finite element program: The portal of damage. The purpose of the program is the numerical simulation of reinforced concrete framed structures, typically buildings, under earthquakes or others exceptional overloads. The program has only finite elements based on lumped damage mechanics. This is a theory that combines fracture mechanics, damage mechanics and the concept of plastic hinge. In the case of reinforced concrete frames, the main mechanism of deterioration is cracking of concrete. Cracking in a frame element is lumped at the plastic hinges. An expressiion for the energy release rate of a plastic hinge is proposed. Cracking evolution in the plastic hinge is assumed to follow a generalized form of the Griffith criterion. The behavior of a plastic hinge with damage is described via the effective stress hypothesis, as used in continuum damage mechanics. The portal that can be accessed using any commercial browser (explorer, netscape, etc.) allows to: a) Create an account in a server. b) Make use of a semi-graphic pre-processor to create an input file with a digitalized version of the structure. c) Run the dynamic finite element program and monitor the state of the process d) Download or upload input and output files in text format e) Make use of a graphic post-processor.

### UTILIZATION OF OBJECT-ORIENTED TECHNOLOGIES AND DESIGN PATTERNS IN THE DEVELOPMENT OF SOFTWARE FOR STRUCTURAL DYNAMICS – ID 968

*P. Komodromos, University of Cyprus, Cyprus*
*P. Polycarpou, University of Cyprus, Cyprus*
*L. Papaloizou, University of Cyprus, Cyprus*
*M. Phocas, University of Cyprus, Cyprus*

The substantial increase in the processing speed and computational power of current computers and the growing size and complexity of new software applications raise the relative importance of maintainability, reusability and extensibility requirements for modern engineering software. Object-oriented programming (OOP) technologies can be used together with design patterns (DP) to develop flexible software for engineering applications, such as numerical simulators for dynamic analysis of structural systems under earthquake excitations. Instead of using procedure-oriented programming languages, a modern OOP approach using DP is suggested enabling easy adjustments and extensions of engineering software to facilitate parametric studies for research purposes. DP is the latest development in software development, standardizing certain software patters that recur in software architecture and implementation. Although design patterns have been widely adopted in computer science and modern business applications, they have not yet been utilized in engineering applications. The combination of OOP and DP offers the flexibility and extendibility that a research tool should have to accommodate the frequent changes, without sacrificing computational performance and reliability of the results. This research work aims to demonstrate how modern software methodologies and techniques can be utilized in the development of modular and expandable software that can be easily adjusted to facilitate various research objectives, such as parametric studies, in the area of earthquake engineering. A software application that simulates seismically isolated buildings, including potential pounding effects, is implemented to demonstrate the benefits that can be gained from utilizing OOP and DP in engineering applications. Furthermore, the paper addresses performance concerns regarding computational overhead and scalability issues of these technologies, evaluating the impact of their usage in engineering applications compared with procedural programming languages.

### ADVANCED FLAG-SHAPE SYSTEMS FOR HIGH-SEISMIC PERFORMANCE – ID 991

*K. Weng Yuen, University of Canterbury, New Zealand*
*S. Pampanin, University of Canterbury, New Zealand*
*A. Palermo, Technical University of Milan, Italy*
*A. Carr, University of Canterbury, New Zealand*

Remarkable improvements and accomplishments have been

observed in seismic engineering in the recent past with the definition and development of high-performance seismic resistant systems, able to sustain major ground motions with limited level of structural damage. The developments of systems, connections, dissipation devices exhibiting a "flag-shape" behaviour, characterized by the combination of self-centering and dissipation capacity, allow to significantly reduce the expected level of damage,e when compared to traditional monolithic systems, by controlling the maximum displacements to target values and limiting to negligible values the residual (permanent) deformations occurring after a seismic event.

In this contribution, the concept of advanced flag-shape systems (AFS) is proposed based on further refinements and improvements of "traditional" flag-shape systems. By appropriately combining in series and/or in parallel alternative forms of dissipation (yielding, friction or viscous) in addition to the re-centering capacity, provided by unbonded tendons or Shape Memory Alloys, advanced high-performance seismic resisting systems can be achieved, able to counteract the effects of both far field and, more effectively, near field events, which are characterized by low number of cycles and high velocity pulse.

The conceptual behavior and key parameters in the design process of alternative configuration of AFS systems will be discussed through numerical investigation on SDOF systems subjected to suites of either far field and near-field record events. In conclusion, suggestions for incorporating a velocity-based design approach within a displacement-based design methodology of AFS systems will be given.

## POSTBUCKLING AND CYCLIC BEHAVIOR OF BRACING MEMBERS USING FIBER ELEMENTS – ID 1010

*B. Asgarian, K.N.Toosi University of Tech, Iran (Islamic Republic Of)*

Bracings as lateral load resistant system are one of the most commonly used methods to resist lateral loads such as earthquake. Bracing undertakes large lateral displacement and provides energy dissipation in the nonlinear range of deformations when the structure is subjected to strong ground motion. As the bracing members are subjected to cyclic tension and compression axial loads, they may buckle and the load resistance ability is reduced by increasing member lateral displacement Bracing members during compressive load up to buckling remain essentially straight and elastic. After buckling of bracing members at its elastic or elasto-plastic critical load, the magnitude of axial load decreases with increasing lateral deflection of member mid span. The bracing member thus loses strength in the post buckling range rapidly and has little stiffness in the buckled configuration. Also, such a brace does not return to its original geometry. Remaining and increasing residual lateral displacement in each of the load cycles made load resistance abilities and energy dissipation of the system reduced with each load reversal. In this paper, a nonlinear fiber element for the simulation of buckling, post buckling, and hysteric responses of bracing members is formulated and implemented in the nonlinear program DRAIN-3DX. In this element both material and geometric nonlinearity are considered. The element is applied to simulate post buckling and hysteric response of pinned and fixed braces subjected to cyclic loading. The results are in good agreement with available results, i.e., experiment and other analytical models data in terms of buckling load, load-deformation curve, strength, and stiffness degradation.

## SENSITIVITY ANALYSIS OF RESPONSE SURFACE METHOD FOR ASSESSMENT OF SEISMIC FRAGILITY OF RC STRUCTURES – ID 1018

*N. Buratti, University of Bologna, Italy*
*B. Ferracuti, University of Bologna, Italy*
*M. Savoia, University of Bologna, Italy*

In the last decade, methods to evaluate structural seismic risk received great attention. The aim of these techniques is to take variability of seismic action and random nature of mechanical/geometric parameters into account. In the present work, a general and sophisticated method for seismic fragility analysis is studied. Hazard and fragility analysis of the structure are carried out separately and the latter is performed using a response surface (RS) model. As for structural capacity, a RS model with block effects is used, a series of accelerograms is adopted and capacity is then defined as a function of Sa(T). The adopted RS can be a linear or quadratic polynomial relation between the response parameter (i.e. Sa(T)) and the random variables that explicitly and implicitly govern the structural response. Tipically mechanical properties and gravity loads are taken as explicit variables, while randomness in seismic action is considered through implicit variables. The RS is calibrated through numerical data obtained by non-linear dynamic numerical simulations which are performed using recorded accelerograms. In order to have a good compromise between number of analyses and reliability of results, the central composite design CCD is adopted to plan these simulations which are then subdivided in blocks associated to different recordings. In this paper, sensitivity of results concerning three different aspects is studied: degree of polynomial function adopted for RS, the criterion adopted to select value of response spectrum for the structure in each numerical simulation, improved methods for defining CCD. In order to investigate these aspects, artificial accelerograms are used in simulations. In sensitivity analyses, they are preferable with respect to recorded ones because these latter are not in sufficient number to form an homogeneous statistical sample and they typically introduce a great dispersion in results, fading the aspects under investigation.

## SENSITIVITY OF SEISMIC DEMAND OF R/C FRAME BUILDINGS – ID 1029

*S. Jankovic, University of Montenegro, Yugoslavia*

Various sources of uncertainty are inherently included in evaluation of building performance under the earthquake loading. Among those are: intensity measure of ground shaking, characteristic of ground motion other than intensity, mass, damping, strength and stiffness of elements. This paper investigates which of these uncertain input parameters are more significant to the structural demand has been done. This investigation is performed on four reinforced concrete frame buildings with different number of stories (4, 6, 8 and 12) designed according to Eurocode 8.

Relatively simple deterministic sensitivity analysis has been adopted for this study to determine the importance of input parameter. First, assuming the probability distribution of each parameter, best estimate as well as lower-bound and upper-bound values have been selected. Then, change in output performance resulting from varying one input parameter from its lower-bound to upper-bound value, while holding all others at their best-estimate value is measured. Seismic responses of R/C frames are shown using two engineering demand parameters: maximum of all interstory drifts, parameter which is used in the literature as an indicator for collapse and average of the maximum interstory drifts in each story, which may be related to nonstructural damage. The results are graphically presented using so-called tornado-diagram.

Obtained results show that seismic responses of R/C frames are more sensitive to uncertainty in ground motion characteristics (intensity measure and other properties) than that in structural properties (mass, damping, strength and stiffness). This conclusion suggests that gross uncertainty on seismic performance can be best reduced via better understanding of ground motion characteristics.

Key words: sensitivity analysis, nonlinear time-history analysis, reinforced concrete frames, seismic demand

## COMPUTATIONAL METHODS APPLIED TO THE SEISMIC MARGIN ASSESSMENT OF POWER PLANTS AND EQUIPMENTS – ID 1038

*F. Voldoire, EDF/DRD/AMA, France*

This paper presents a survey of the research works carried out by Électricité de France to determine the safety margins on seismic events, for existing structures and buildings. Since

the first design of the power plants, dams, and other industrials equipments, the new seismic risk requirements have increase the peak ground acceleration level input that have to be supported without collapse by the structures and components. This evolution leads to determine the safety margins and eventually the design weaknesses. These safety margins can be assessed by non-linear and coupled structural dynamic finite element methodologies, associated to probabilistic approaches, and compared with engineering conventional approaches. These calculations have been qualified by comparison with experimental results. We take into account material dissipative constitutive relations, large transformation kinematics, soil and fluid structure interactions, and more refined loading descriptions and structural elements modelling. We present particularly the principal characteristics of the non-linear and coupled finite element methodologies that are developed and based on the general-purpose non-linear finite element software Code_Aster, including a frequential coupling with specific soil and fluid structure interaction software ProMiss3D. Finally, we present the on-going R&D activities performed by Électricité de France in this field. The major topics are: robustness and performance of direct non-linear transient dynamic simulations applied to elastic-plastic buckling (steel frameworks, tanks), damaging behaviour of reinforced concrete structural elements (slabs, walls), uncertainties treatment, seismic response of sliding-toppling structures, seismic near-field non-linear behaviour of unsaturated soils for embankment dams stability analyses...

REFERENCES: Code_Aster, general public licensed structural mechanics finite element software, Internet site : http://www.code-aster.org.

## PROGRESSIVE COLLAPSE OF RC STRUCTURES: SEISMIC AND MANMADE HAZARDS – ID 1039

*M. Sasani, Northeastern University, United States*

Progressive collapse is defined as the spread of an initial local failure from element to element eventually resulting in the collapse of an entire structure or a disproportionately large part of it (ASCE 7-02). Following a local failure, the ability of a damaged structure to redistribute and carry gravity (vertical) loads is the controlling factor in the prevention of structural collapse. There is a lack of proper understanding of system level collapse as well as proper analytical modeling techniques for use in collapse analysis of structural systems. Mainly because of these reasons, in seismic rehabilitation of structures, FEMA-356 (2000) defines near-collapse acceptance criteria at the element level. Such criteria are significantly more conservative (an order of magnitude) than those used in other current provisions for assessment of collapse of structures subjected to manmade hazards (such as explosions and impacts). One reason for such a significant difference is that FEMA-356 neglects potential development of catenary (cable like) action in beams.

Utilizing experimental results from tests recently carried out by the authors, calibrated and verified element models capable of modeling catenary action in beams under large deformations are utilized to study collapse of RC structures subjected to seismic ground motions as well as manmade hazards. The need for improved analytical modeling such as proper modeling of floor systems is demonstrated. System level collapse analyses of three-dimensional models of RC structures following seismic element failure are carried out and the results are compared with those based on FEMA-356 criteria. The effects of the level of lateral resistance of structures on resisting manmade hazards are evaluated and discussed and recommendations are made.

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## ASSESSING THE RESPONSE OF STRUCTURAL FRAMES TO PULSE TYPE GROUND MOTIONS – ID 1052

*A. Meshkat Dini, Amir Kabir Univ. of Technology, Iran (Islamic Republic Of)*

In this paper some finite elements are proposed for analysis of bending frame systems subject to pulse type ground motions. In the process of investigations, the effect of shear – flexure interaction in a beam – column element, in overall behavior of earthquake resistant system, is considered. Static and dynamic analyses of some example systems indicate the efficiency and accuracy of the mentioned finite elements.

## NUMERICALLY ESTIMATED RESPONSE OF TWO DIFFERENTLY DESIGNED DUAL RC SYSTEMS – ID 1058

*L. Martinelli, Politecnico di Milano, Italy*

Recently, Displacement Based Design methods have become a possible alternative to the concept of the force based design methods, generally adopted in seismic codes. The assessment of the performance for such new design methods only through the experimental testing of real specimens is, of course, not possible. Experimental results, however, are the base on which numerical models, representative of the structure, can be assembled. Once available and validated, these numerical models may be employed to asses the performance of the design method at study.

This work is related to the estimation of the performance of two differently designed dual reinforced concrete systems: one designed according to the Displacement Based Design method proposed in [1], the other according to Eurocode8. Each system is composed of a frame part in parallel to coupled shear walls. The structure composed of the two dual systems, working in parallel, has been tested with the pseudodynamic technique [2]. Starting from a numerical model of the global type, assembled using column fiber elements [3], it has been possible to study the response of two new structures, each one entirely composed only of elements designed according to the DBD proposal in [1], or according to Eurocode8. Each structure has been analyzed for ten different natural accelerograms, selected to have a mean pseudoacceleration spectrum similar to the Eurocode8 one. The results in terms of global and local damage indexes are compared.

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## A POTENTIAL WELL ANALOGUE OF ELASTO-PLASTIC SEISMIC RESPONSE – ID 1061

*C. Taylor, University of Bristol, UK*
*M. Adom-Asamoah, Univ of Science and Technology, Ghana*
*N. Alexander, University of Bristol, UK*

The move towards a performance based engineering approach for the seismic design of buildings requires a thorough understanding and effective models of the accumulation of damage during the seismic event. Current seismic design approaches tend to focus on forecasting maximum displacements, rather than cumulative damage. These methods are reasonably successful in forecasting collapse, but their extension to forecasting of cumulative damage is problematic and requires a deeper understanding of the controlling influences of key parameters.

The aim of this paper is to explore the fundamental dynamics of archetypal non-linear elasto-plastic single degree of freedom systems from the perspective of the classical mechanics model of the escape of a mass particle from a potential well. Thompson and Stewart (2003) have shown the power of this model for understanding the capsize of ships in beam seas. The paper will show how this model can be extended to non-linear seismic response of buildings and thereby

aid the exploration and characterisation of the key controlling parameters. In particular, it will be shown how the kinematics of the elasto-plastic potential well defines the acceptable performance domain in the phase-control parameter space. As a consequence it will be argued that performance based design should seek explicitly to control both velocity and displacement, rather than just the latter.

Borrowing techniques from the field of non-linear mathematics, it will be shown how the potential well model can explain why the time history characteristics play such an important role in non-linear seismic response. These techniques reveal the detailed parameter sensitivities of the system response using tens of thousands of time history simulations. The results relate to, and provide a broader context for, published detailed studies of non-linear response spectra.

### ON THE DIAPHRAGMATIC BEHAVIOUR OF ROOF SYSTEMS – ID 1085

*L. Ferrara, Politecnico di Milano, Italy*
*G. Toniolo, Politecnico di Milano, Italy*

It is well known as the effective response of a structure to seismic actions basic relies on the diaphragmatic behaviour at storey and roof level: due to their in-plane stiffness and strenght they have to transfer inertia forces to vertical structural elements and ensure that they act together to resist the earthquake induced forces. Cover systems in precast r/c industrial buildings generally employ precast prestressed roof elements, often featured by non-conventional cross-sectional shape, and furthermore separated by interposed skylights. The diaphragmatic behaviour of these roof systems has to be hence carefully checked, in order to provide a reliable evaluation of seismic actions on the structures, e.g. through a proper value of the behaviour factor q. The new Italian seismic code, for example, provides, as far the behaviour factor q is concerned, different specifications, right based on the reliability of the diaphragm action the roof system is able to develop. In this work, starting from a reference sample building 30mx50m (two bay 15 m long and 5 10 m spans), the problem has been analysed, through modal analyses, considering different roof systems (Π elements both connected between themselves and with interposed skylights, Y elements with interposed skylights) and investigating the role of different parameters governing the problem (beam and roof element span, type of roof system and connection system etc.). The efficacy of proposed simplified design approaches will be also checked.

### ANALYTICAL ASPECTS OF SHEAR CORE WALL MODELING IN TALL BUILDING STRUCTURES – ID 1101

*M. Tehrani Zadeh, Amir Kabir Univ. of Technology, Iran (Islamic Republic Of)*
*A. Meshkat Dini, Amir Kabir Univ. of Technology, Iran (Islamic Republic Of)*

Modeling of core wall structures in tall buildings needs to use special considerations in conjunction with theoretical procedures and engineering applications of this lateral load resistant system. Considering these aspects, produce some analytical points of view in the field of modeling and analysis of shear core wall system in tall buildings. This paper deals with the application of some finite elements and solid wall models, used in analysis of core wall systems in tall buildings. Further more, the ability of the mentioned models for estimating the response of these lateral load systems are discussed.

### COMPUTER PROGRAM FOR THREE-DIMENSIONAL NONLINEAR DYNAMIC ANALYSIS OF SEISMICALLY ISOLATED STRUCTURES – ID 1110

*P. Roussis, University of Cyprus, Cyprus*
*P. Tsopelas, The Catholic University of America, United States*
*M. Constantinou, University at Buffalo, United States*
*R. Buchanan, AMEC Oil & Gas, UK*
*A. Reinhorn, University at Buffalo, United States*

This paper presents 3D-BASIS-ME-MB, a recently-enhanced version of program 3D-BASIS-ME. The 3D-BASIS suite of computer programs was developed for the nonlinear dynamic analysis of three-dimensional seismically isolated structures. Capable of modeling various types of isolation devices with strong nonlinearities, including an element for modeling the newly-developed uplift-restraining XY-FP isolator, 3D-BASIS-ME-MB provides a versatile tool for analysis and design of complex structures with modern isolation systems. Program 3D-BASIS-ME-MB offers the capability to analyze multiple superstructures (up to five separate superstructures) on multiple bases (up to five bases) and the capability to capture the effects of lateral loads on bearing axial forces, including bearing uplift. Two examples of seismically isolated structures are used for verifying 3D-BASIS-ME-MB and demonstrating its capabilities. The first example is a seven-story model structure that was tested on the earthquake simulator of the University at Buffalo and was also used as a verification example for program SAP2000. The second example is a two-tower, multi-story structure with a split-level seismic isolation system. In both examples the analyzed structure is excited under conditions of bearing uplift, thus yielding a case of much interest in verifying the capabilities of analysis software.

### SEISMIC DYNAMICS OF NON-LINEAR ELASTIC DAMAGE RESISTANT STRUCTURES – ID 1111

*O. Oddbjornsson, University of Bristol, UK*
*N. Alexander, University of Bristol, UK*
*R. Sigbjornsson, University of Iceland, Iceland*
*C. Taylor, University of Bristol, UK*

Damage resistant building structures are of growing interest. They exhibit softening non-linear elastic (as opposed to elasto-plastic) characteristics, but with recoverable displacements. The softening elastic behaviour provides a degree of resilience during seismic loading, but does not lead to significant permanent damage. Consequently, the post-earthquake serviceability of the building is not impaired. Post-tensioned, pre-cast concrete frames are a typical example. Here, the non-linear elasticity arises primarily from geometric distortions of the post-tensioning forces.

Non-linear elastic structures have an important difference from elasto-plastic structures in that all the strain energy imparted into the structure is recovered on unloading. This substantial recoverable strain energy can have a dramatic effect on the system dynamics, leading to chaotic-type motions that are very sensitive to parameter variations. As a consequence, design spectra developed for elasto-plastic type structures are not necessarily suited to the design of non-linear elastic structures. A crucial aspect of non-linear elastic system design is the introduction of additional damping mechanisms or devices that can exert an acceptable degree of control over the dynamic performance; but to achieve this goal it is essential to have a deep understanding of the fundamental and rather complex non-linear dynamics issues.

This paper will apply techniques from the non-linear mathematics field to explore the fundamental dynamics of non-linear elastic structures under seismic loads. Tens of thousands of nonlinear response-history analyses, using artificial earthquake time series derived from a common power spectrum, will be used to explore the phase-control parameter space of the system. It will be shown how the basic structure of this space can be related to the fundamental damping and stiffness parameters of the structure, which are the primary control parameters available to the designer. Conclusions will be drawn as to how elasto-plastic based design approaches might be adapted better to non-linear elastic systems.

### CLOSED-FORM SOLUTIONS FOR RESPONSE OF YIELDING SDOF OSCILLATORS TO SIMPLE PULSES – ID 1125

*G. Mylonakis, University of Patras, Greece*
*E. Voyagaki, Consultant, Greece*

Analytical solutions are presented for the inelastic re-

sponse of single-degree-of freedom yielding oscillators to simple ground acceleration pulses. These motions are typical of near-fault earthquake motions generated by forward rupture directivity and may inflict damage in the absence of substantial structural strength and ductility. Four basic pulse waveforms are examined: (1) triangular; (2) sinusoidal; (3) exponential; (4) rectangular. A numerical study is first presented of the effect of oscillator period, strength, damping, post-yielding stiffness and number of excitation cycles, on inelastic response. The effect of high-frequency motions ("higher harmonics") that override actual earthquake pulses is discussed. Results are presented in the form of dimensionless graphs and regression formulas that elucidate the salient features of the problem. It is shown that conventional R-$\mu$ relations may significantly underestimate ductility demand imposed by near-fault motions.

The second part of the article concentrates on elastic-perfectly plastic oscillators. Closed-form solutions are derived for post-yielding response and associated ductility demand. It is shown that all three ground motion histories (i.e., acceleration, velocity, and displacement) control oscillator response – contrary to the widespread view that ground velocity is of leading importance. The derived solutions provide insight on the physics of inelastic response, which is often obscured by the complexity of numerical algorithms and actual earthquake motions.

## SIMPLIFIED STRUCTURAL MODELS FOR SEISMIC ANALYSIS – ID 1129

*A. Aronchik, NBRI-TECHNION, Israel*
*D. Yankelevsky, NBRI-TECHNION, Israel*

The preparedness for a strong earthquake requires attention to the entire built environment. Some of the built infrastructures like storage tanks are rather different from the common buildings, to which much of the attention is given. Powerful software with options for detailed simulation of liquid – soil - structure interaction, and the capabilities of advanced structural analysis including buckling and post-buckling stages etc., are available for structural analysis of liquid storage tanks. Thus numerical simulations of liquid storage tanks require a high level of expertise and are time consuming. The complexity involved in this detailed analysis may be reduced by using various simplifications, depending on the stage of analysis. Sometimes, these simplified models allow a fast and economic analysis that yields very good predictions. The simplified methods may be tailored to solve a certain group of problems (estimate the periods of vibration, total base overturning moment and shear force) or be used together with common structural analysis software. The latter option opens the option to solve a large variety of different problems with modest requirements of skills and time. The Housner-Clough-Veletsos mechanical model, that was introduced into major codes and regulations (e.g. API-650, ACI-350, Eurocode 8), could be successfully implemented in such codes for simulation of storage tank structure - liquid interaction. The present paper describes a new simplified approach developed by the authors, for structure-liquid tank analysis that is composed of simplified structural models using a general-purpose finite element package for structural analysis and the Housner-Clough-Veletsos mechanical model-analog methodology. Two- dimensional and three- dimensional problems were studied with the proposed model and the obtained results were compared with existing analytical procedures. The proposed model results agree well with analytical exact solutions. It may be used to efficiently obtain the response characteristics with satisfactory precision and a modest input of resou

## ALGORITHM FOR THE COMPUTATION OF ACCELERATION DEMANDS ON EQUIPMENTS INSTALLED IN MULTI-STOREY BUILD – ID 1142

*D. Melro, Instituto Superior Técnico, Portugal*
*J. M. Proenca, Instituto Superior Técnico, Portugal*
*C. Sousa Oliveira, Instituto Superior Técnico, Portugal*

The operation and integrity of sensitive equipment (e.g. advanced medical diagnosis and therapy equipment) is dependent on the expected acceleration levels and on global equilibrium considerations. These equipments are generally termed "acceleration-sensitive", in contrast with the "drift-sensitive" equipments (e.g. plumbing) in what regards its sensitivity to earthquake effects on buildings. National and internationally applicable standards present empirically-based expressions to compute the expected acceleration levels at a given storey level, considering the location (storey level) of the equipment and its frequency/damping characteristics. The presented review and comparison of these expressions indicates some discrepancies and lack of sound scientific support. This paper presents an innovative algorithm to estimate the seismic demands on acceleration-sensitive equipments placed in a multi-storey building. This algorithm allows also for the computation of the forces that develop at the supports and fixtures of the equipment. The presented method is based on the dynamic characteristics of the building (frequencies and mode shapes), and the equipment, on the mass and damping properties of the building and equipment, and on the seismic power spectral density. This method can also be used to define the floor acceleration response spectra. A simplified method is also introduced by taking into account only the most relevant vibration mode shapes of the building.

## DESIGN OF EARTHQUAKE RESISTANT CIVIL STRUCTURES USING EIGENMODE DESIGN CONTROL – ID 1154

*P. Rosko, TU Wien, Austria*

The aim of the paper is the optimal model design of earthquake resistant civil structures. To reach the goal we need generally to minimize the dynamic response of the structure but the moving of the structure or parts of it in a "safe" direction is allowed. Usually the following approach is used: Civil structures under dynamic loading are preparatory designed on the base of experience or on the base of simply design rules. Most of these rules are included in codes (e.g. Eurocode 8). In the next step follows the quasistatic or dynamic analysis of the predesigned structure. The repeated analysis a redesign optimizes the dynamic characteristics of the model. In the paper is proposed the reverse approach: The dynamic response of the structure is designed in advance. The theory of modal analysis is used. The linear response of the model can be approximated by the sum of eigenmodes. The importance of higher eigenmodes decreases. Only the first eigenmodes are "designed". The structural dynamic parameters of eigenmode-design are mass and stiffness distribution and support positioning. The parameters and the eigenmodes depend on each other. In the next step the appropriate parameters are calculated. The examples using the above mentioned approaches of the design are compared. For all calculations the programs ANSYS and MATLAB are used. Application of the "reverse" approach results new structural applications.

## EARTHQUAKE VULNERABILITY ASSESSMENT OF A STEEL STRUCTURE – ID 1161

*I. S. Ginju, Technical University of Civil Engineering Buchares, Romania*
*M. Ieremia, Technical University of Civil Engineering Buchares, Romania*

The paper present the earthquake vulnerability assessment of an industrial building, placed in a high Vrancea earthquake area from Romania. The site is corresponding to earthquake level VIII on MSK scale. The Building is used for distribution coal, nitrogen and oxygen at 4 technological levels to a furnace. The strength structure is made up of many-stored bracing steel frames, being assemblied by welding. The building has 4 levels of 6m height, one span of 6m and two bays of 6m. In the gable, the building has two consoles about 3.20m and 1.95m respectively. The building is supported by foundation plates untill the –2.20m depth and by drilling piles of 800mm diameter beyond that. To find the earthquake performance of the structure was the design based on displacement applied. The capacity spectrum method was used to find the performance point of structure. Two type

of analysis was performed: the modal analysis and the pushover analysis. In the pushover analysis the von Mises constitutive law was used for modelling of elasto-plastic behaviour of steel. The parameters of fragility functions were calibrated with the probabilistic Monte Carlo Simulation method in conjunction with the Latin Hypercube Sampling technic. Two random input variables were considerated: the Young's modulus described by a Gaussian probability distribution with standard deviation of ±5% and the yield stress caractherized by a lognormal probability distribution with standard deviation of ±15%. The result of the analysis is a certain damage state expressed in terms of probabilities. Finaly the information about the earthquake vulnerability of structure was compared with the results from a classical expertise of the structure. The paper point out the necessity to perform the vulnerability analysis in the investigation of existing building.

## AN ALTERNATIVE PROCEDURE FOR ACCIDENTAL ECCENTRICITY APPLICATIONS IN DYNAMIC ANALYSES OF BUILDINGS – ID 1166

*Y. Fahjan, KOERI, Bogazici University, Turkey*
*C. Tuzun, KOERI, Bogazici University, Turkey*
*K. Joseph, Prota Bilgisayar, Turkey*

Most building codes require that accidental torsion to be considered at each floor level of an asymmetric-plan building in both equivalent static load procedure and dynamic analyses. The computations of accidental torsional moments in equivalent static load procedure are straightforward and already implemented in most of building analysis tools. However, the application of accidental torsion in dynamic analysis can be performed in one of the following two basic approaches: 1) Moving the center of mass by the required amount of eccentricity in either direction. This will lead to change in global stiffness matrix of the system, therefore natural frequencies and modal parameters are need to be computed for each eccentricity cases. 2) Run static analyses considering torques at each story level to approximate accidental torsion for each eccentricity cases then combine the results with the dynamic load results. In this study an alternative procedure for the application of accidental torsion in dynamic analyses is proposed. The methodology is based on dynamic modal superposition technique by applying of accidental torsion to global force vectors related to each modal shapes. Global displacement vectors are computed for each modal shape. Then, corresponding global force vectors can be easily computed using global mass matrix, eigenvalues of the system and global displacement vectors. For each mode shape, the accidental torsional moments of the global force vector can be updated by required amount of eccentricity in either direction. Static analysis will be carried out in order to find the modified global modal displacement vectors and the internal forces for each members can be computed for each modal shape. The nodal displacements, and internal force results can be combined using standard modal combination techniques. The proposed procedure can be applied for building with rigid and/or flexible diaphragms and suitable to be implemented in building analysis tools.

## STUDY CASE: A MULTISTORY HOTEL BUILDING REHABILITATION – ID 1182

*I. Benke, PROIECT S.A., Romania*

In Romania the structures are designed to support not only gravity loads, but they need to resist lateral forces from earthquakes. In Sovata city –Romania a multistory hotel /structure: reinforced concrete columns, Vierendel beams and reinforced concrete walls/ where tried out by a big earthquake in 4. March 1977. The paper presents a case-study of the reinforcement of structural elements. The structure is analyzed in three-dimensional finite element model, using the program AXIS VM. Through this way the displacement and the vibration periods of the structure are obtained. Some conclusions are finally presented.

## DYNAMIC RESPONSE OF SUBMERGED FLOATING TUNNELS SUBJECTED TO SEISMIC AND HYDRODYNAMIC EXCITATION – ID 1187

*M. Di Pilato, Politecnico di Milano, Italy*
*F. Perotti, Politecnico di Milano, Italy*
*A. Feriani, University of Brescia, Italy*

In the paper a numerical procedure is described for the dynamic analysis of seabed anchored floating structures, with particular reference to the so called Archimedes Bridge solution for deep water crossings; attention is mainly devoted to the design solution encompassing slender bars as anchor elements. For modelling these elements two numerical tools have been extensively explored. First, the refinement of a geometrically non-linear finite element, developed in previous work, has been proposed, aiming at a better representation of the local transverse oscillations of the bar. To this purpose, new element coordinates are introduced, related to higher order harmonic shape functions. Element capabilities are also extended to non-linear modeling of hydrodynamic loads due to steady current and wind waves. For comparison purposes a different 3D beam element was also developed, based on the classical co-rotational formulation; this allows to accommodate large rotations, by separating the effects of the rigid body motions from the bar deformation. Oran's joint orientation matrix is used to deal with the non-vectorial characteristic of finite rotations. Both, the former enhanced element and the co-rotational element are implemented in a numerical procedure for the dynamic time domain step-by-step analysis of non-linear discretized systems; consistently, hydrodynamic and seismic loading is introduced by generating artificial time-histories of spatially variable seismic motion and wind waves. An example of application is shown regarding the behavior of the dynamic model of a submerged tunnel proposed for the Messina Strait crossing. The model is subjected to an extreme multiple-support seismic loading having a PGA of 0.64 g and to an extreme wave loading with significant wave height of 16 m. The dynamic behavior in the two loading situations and for both numerical tools, are illustrated and compared, showing interesting facets, especially in terms of interaction between the tunnel and anchoring bars oscillations.

## APPLICATION OF PUSHOVER ANALYSIS PROCEDURES FOR PREDICTING THE SEISMIC RESPONSE OF RC STRUCTURES – ID 1199

*P. P. Diotallevi, DISTART - Dept. of Civil Engineering, Italy*
*L. Landi, DISTART - Dept. of Civil Engineering, Italy*

In the practical design applications the evaluation of seismic response is usually based on linear elastic structural behaviour. However this approach may be not effective in limiting the damage levels of the buildings. The non-linear dynamic analysis is the most rigorous method, but it is still too complex for design use. Therefore the pushover analysis seems to be a more rational method for estimating the inelastic behaviour. Some problems characterize the pushover analysis. One of these is the definition of a proper lateral load distribution. It is well known that the shape of the lateral load distribution affects significantly the results of the analysis. In the last years adaptive procedures were developed in order to take account for the variations of the load shape in the inelastic range. These variations could be significant for irregular buildings in elevation. This work would give a further contribution to the assessment of pushover procedures. A wide numerical investigation is performed in order to assess the capability of the pushover procedures recently proposed and to identify their advantage and disadvantage. Pushover procedures as conventional, modal and adaptive procedures, are applied and compared with non linear dynamic analyses. The analyses are performed considering a set of RC plane-frame buildings characterized by high and low number of storeys and by regular and irregular configurations. The dynamic analyses are carried out considering twenty natural acceleration records, selected within the most frequently used records. These analyses are repeated considering for each record by increasing the values of seismic intensity. The pushover results are compared with incremental dynamic analyses results. The results are examined in terms of pushover curves and also in terms of displacement, drift

and damage profiles along the height.

### STRUCTURAL DAMAGE DETECTION WITH THE IMPROVED MATRIX TRANSFORMATION METHOD – ID 1223

*H. Guerrero, Institute of Engineering, UNAM, Mexico*
*J. A. Escobar, Institute of Engineering, UNAM, Mexico*
*R. Gomez, Institute of Engineering, UNAM, Mexico*

A damage detection method based on the transformation matrix that operates on the global stiffness matrix a structure, condensed on the primary degrees of freedom, is presented. The method is based on the fact that the transformation matrix for the damaged state can be initially estimated from the corresponding to the non damaged state, by using an iterative procedure.

Initially, the method has been applied to building models. In these structural systems, it is common the presence of symmetrical structural elements with same stiffness. For the same damage magnitude, the symmetrical structural elements shall produce the same variation in the condensed stiffness matrix. The detection of damage in these elements is achieved through an "independent element" which is proportional to the number of symmetrical elements. By using this assumption, a good approach has been obtained in the estimation and localization of damage.

In this investigation, a necessary refinement of the solution has been achieved and is presented. Now, it is possible to detect damaged structural elements of the buildings, and the magnitude of this damage with a better accuracy.

The objective of this work will be to present this new formulation applying it to the study of building structures.

### TWO-STEP SEISMIC ANALYSIS OF COMPLEX STRUCTURES – ID 1230

*O. Gurbuz, Bechtel Corp., United States*
*D. Watkins, Bechtel Corp., United States*

The design of safety related reinforced concrete structures relies on SASSI code for soil-structure interaction analysis. Acceleration profiles and ISRS are obtained. This is the 1st step of the "Two-Step Seismic Analysis Method." The 2nd step analysis is performed using software with a detailed model for stress analysis and in combination with other loads. The analysis uses SASSI seismic responses, usually acceleration profiles as input. The 2nd step analysis is conservative for concrete members, but its adequacy for steel structures was uncertain. The question centers around member forces that may be affected by the higher modes. Therefore, there is a need to demonstrate the adequacy of the two-step method using structural models that could be affected by the higher modes. This paper summarizes an approach to validate the two-step seismic analysis method for two large reinforced concrete structures with steel braced frame as the top floor. The first step analysis was carried out using a coarse finite element mesh for the concrete. A second model of the concrete structure was prepared for the second step analysis. The steel frame details were essentially the same in both models. The first step analysis was completed using the SASSI computer code and acceleration profiles (and ISRS) were obtained considering soil variability. SASSI analysis results were processed to determine the selected steel frame member forces using the transfer functions. Thus, accurate steel member forces were obtained from the first step dynamic analysis. Using the accelerations profiles, the detailed finite element model was analyzed statically with SAP2000. All element forces were extracted for design. The member forces were compared with those from the SASSI analysis. Comparison validated the member forces obtained from the two-step approach. The results are included in the paper. The new method is being added to the next version of ASCE4-98.

### APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNIQUES TO STRUCTURAL DYNAMIC PARAMETER IDENTIFICATION – ID 1235

*G. Wang, Chaoyang University of Technology, Taiwan*
*F. K. Huang, Tamkang University, Taiwan*

Structure properties may be deteriorated and degraded with time in an unexpected way due to randomness in the environment and loadings over its lifetime. In particular, when a structure is exposed to strong earthquake, the properties of the structure may be changed and its behavior after an earthquake can be different from that before the earthquake. In order to realize the dynamic behavior of structural systems, we can determine the dynamic models and parameters by system identification techniques. In this study, the single layer neural network is first employed to identify the system parameters of both the SDOF system and the MDOF system. There are two kinds of earthquakes to be used as the system input, one is the artificial earthquake, and the other is the real earthquake. The associated system response is then calculated assuming the system parameters. In addition to the traditional batch mode algorithm, the improved batch algorithm is also used as the training algorithm, while performing the single layer neural network to the above identification problems. The validity and the efficiency of the proposed algorithms are explored by comparing the results of the predicted response with the measured response for both the SDOF system and the MDOF system with or without noise contamination. Furthermore, the advantages of the genetic algorithm and the above single layer neural network are combined to yield a new identification technique. The network topology is employed to replace the procedure for solving the governing (differential) equation when GA is used to identify the system parameters of both the SDOF system and the MDOF system with or without noise contamination. The comparison is made between the predicted acceleration and the measured one for each case.

### COMPARISON AMONG ASEISMIC DESIGN USING IBC-2003 , EGYPTIAN CODES AND THE GEOPHYSICAL STUDIES – ID 1238

*Y. Elhakem, CRI,NWRC, Egypt*

Recently the International Building Code (IBC-2003) has been released in U.S. in the year 2003. Also the Ministry of Housing in Egypt has published the Egyptian Code for calculation of Loads and Forces in Structures and Buildings in the same year and they stopped the distribution of this code in 2005 to develop it. This code contains major differences in the methods used for calculation of seismic forces than the previous Egyptian Code published in 1993. Also, the Egyptian society for earthquake engineering has published the Regulations for Earthquake Resistant Design of Buildings in Egyptin 1988 and the developed seismic maps for Egypt in 1992. This study has been done to investigate the differences in the design criteria and the factors taken into consideration in each code. They were compared to the IBC-2003 as an example for codes of well developed countries to investigate the advantages and disadvantages of each code to help in the future development of the Egyptian code. The ground acceleration obtained from the previous codes were compared to the expected peak ground obtained from the geophysical studies using the probabilistic hazard analysis of potential ground motion in a specific site in Egypt. Different examples of buildings and a pier of a regulator and bridge structure were solved. Static and dynamic analyses using the Egyptian codes, the IBC-2003 and the geophysical study were done using the finite element method to investigate the effect of the important factors considered by the codes.

### VERIFICATION OF THE ASSUMPTION OF UNCORRELATED MOTION COMPONENTS IN SEISMIC ANALYSIS – ID 1258

*A. Petrenko, St-Petersburg State Technical University, Russian Federation*
*A. Birbraer, Atomenergoproject, Russian Federation*

This paper deals with the verification of the general assumption often used in seismic analysis of structures and components of Nuclear Power Plants (NPP). This assumption states that components of seismic ground acceleration and in-structure response motion are uncorrelated. The criterion used

for considering components as uncorrelated is generally |r_ij| < 0.3, where r is the correlation coefficient for spatial directions i and j in some reference coordinate system. A modified form of this criterion that takes into account the dependence on reference coordinate system is proposed in this paper. Probabilistic analysis of the correctness of the assumption for ground motion is performed with the help of the new criterion based on the 1054 records of earthquakes made in Europe. It is demonstrated that the probabilistic estimation of the realization of such assumption is not less than 64% which proves its correctness. The necessity of verifying the assumption of uncorrelated components of in-structure motion was formulated, for example, by Dr R. P. Kennedy in the beginning of the 1980s. Indeed, contrary to ground motion, the correlation between the components of in-structure motion can be expected instinctively. Possible reasons of strong correlation between motion components in structures are considered in the paper. The influences of an earthquake realization and variations of soil conditions are investigated. Seismic analyses of two reactor buildings and a turbine hall of a NPP show a general possibility for a strong component correlation to arise. At the same time further seismic analyses of the safety related equipment of these buildings show a possibility of acquiring non-conservative results (up to 70% of underestimation). The conclusion is that a zone of the building with high correlation coefficients should be located where special analysis procedure should be performed to avoid underestimated results.

## PROBABILISTIC ASSESSMENT OF ACCURACY OF STANDARD METHODS OF COMBINING SPATIAL SEISMIC RESPONSES FOR STRUCTURES – ID 1260

*A. Petrenko, St-Petersburg State Technical University, Russian Federation*

Seismic qualifications methods of structures developed very intensively from around the middle of the XX century. The accumulation of records of real earthquakes was the basis for this. As a result, powerful approaches were developed by the end of the 70s. They have been used widely for analysis of civil, industrial and safety related structures. However, in the last twenty or thirty years a slowing down of activity in that domain has been observed. At the same time some fundamental changes have happened in development of computers and seismology. Simplified models of structures have been replaced by extremely detailed spatial models with hundreds of thousands of DOF. Databases with thousands of records of past earthquakes are now available. Accumulated data allow verifying the assumptions made under a limited number of earthquake records, those assumptions that form the base of modern theory of seismic engineering. Usually seismic analysis of Nuclear Power Plant structures requires getting maximal total response (displacement, force etc.) combining responses to an excitation in each spatial direction. For instance, this is a typical procedure for response spectrum method. Generally, two combining results methods are used today. These are Square Root of Sum of Squares and Newmark's method or the "100-40-40" rule. Both of them suppose uncorrelated spatial components of an excitation. This paper deals with the probabilistic assessment of the accuracy of seismic analysis using such methods. This assessment has been carried out with the help of 1054 earthquakes records made in Europe in the last thirty years. Models of simple structures (symmetrical and asymmetrical spatial frames, pipeline) were used. Both methods allowed evaluating seismic response within 5% of error with probability that did not exceed 20-60%. It shows the limits of a seismic analysis and the necessity of development of new methods of combining of spatial responses.

## NONLINEAR SEISMIC RESPONSE ANALYSES OF EXISTING R/C BUILDING AND EVALUATION OF SYSTEM COMPONENTS CONTRIBUTION – ID 1309

*M. Faggella, University of Chieti, Italy*
*J. Conte, UCSD, United States*
*J. I. Restrepo, UCSD, United States*
*E. Spacone, University of Chieti, Italy*

Current seismic design codes allow structural engineers to evaluate directly the performance of structures through nonlinear analyses of members and systems. Such analyses are expected to reproduce the actual behavior of structures at different seismic induced displacement levels. This approach is of particular interest in the evaluation of existing structures, which in some cases were designed in absence of seismic regulations. Finite element models of structures can be built using state-of-the-art finite element software, incorporating the nonlinear behavior at the material level. This is often achieved through distributed plasticity models which implement fiber sections for beam elements, and special elements for soil modelling. Such programs allow analysts to reproduce the effects of system components and their interaction with good accu-racy in most cases. Despite the conceptual simplicity of dynamic earthquake analysis, seismic design codes and engineers reveal an interest in using simplified nonlinear static procedures (e.g. static pushover analysis). Since the relative simplicity of conventional and multi-modal pushover procedures has not been proved yet for all classes of structures and response parame-ters, improvements of nonlinear static procedures are currently under development and a com-parative evaluation of static and dynamic analyses is still needed. An existing building (Bone-fro, Italy), damaged in past earthquakes, has been modelled using the structural analysis software framework OpenSees. The objective of this research is to evaluate the influence of each system component (frame, diaphragms, infills, surrounding soil) on the nonlinear seismic response, and weighting each contribution through nonlinear analyses carried out by adding one system component at a time, ranging from the bare frame structure, to the complete frame-infills-slab-soil system. The comparative study of conventional and multi-modal pushover and time history analyses is expected to provide very valuable information on both the analysis methods and the effects and relative importance of the various system components.

## A STUDY IN COMPARISON OF SEISMIC ANALYSIS METHODS SUGGESTED BY TURKISH EARTHQUAKE CODE – ID 1314

*A. Dogangun, Karadeniz Technical University, Turkey*
*R. Livaoglu, Karadeniz Technical University, Turkey*

The main purpose of this study is to examine the differences in results obtained by Equivalent Seismic Load Method, Mode-Superposition Method and Analysis Method in Time Domain suggested by Turkish Earthquake Code. Two series of six and twelve storey buildings are considered for this purpose. Each of series has three buildings which have symmetric, semi-symmetric and unsymmetrical plan geometry. The Finite Element Method is used for modeling of buildings. SAP2000 package program is used to analysis of selected buildings subjected to earthquake. The results obtained by these different methods for the buildings have been compared with each others. Some recommendations related uses of seismic analysis methods are made at the end of the study.

## SEISMIC ASSESSMENT OF RETROFITTED RC COLUMNS USING AN INELASTIC REPAIR ELEMENT – ID 1334

*D. H. Lee, Paichai University, Korea, Republic Of*

In order to evaluate the seismic performance of damaged reinforced concrete members, particularly bridge piers, an inelastic repair element is proposed. The proposed element enables increased characteristics due to structural intervention (i.e., repair or retrofitting) to be accurately reflected to the degraded strength and stiffness of the members. The inelastic repair element having both birth and death time can freely be activated within the user-defined time intervals during static and dynamic time-history analysis. Comparative studies are carried out for reinforced concrete bridge columns that are repaired and retrofitted. Analytical predictions incorporating the developed element show reasonable correlation with experimental results. Also conducted is a nonlinear time-history analysis of a reinforced concrete bridge under multiple earthquakes. Comparative analytical results demonstrate the adequacy and

applicability of the current development. In all, it is concluded that the present element is capable of providing salient features for the healthy evaluation of seismic performance of reinforced concrete members being repaired and retrofitted, and hence seismic stability assessment.

### PERFORMANCE OF TALL BUILDINGS IN NEAR-FIELD EARTHQUAKES – ID 1338

*A. R. Khaloo, Sharif University of Technology, Iran (Islamic Republic Of)*
*P. Ghaderi, Sharif University of Technology, Iran (Islamic Republic Of)*
*S. F. Ghahari, Sharif University of Technology, Iran (Islamic Republic Of)*

In near-field earthquakes, high frequencies usually can not be damped and consequently result in high frequency acceleration. The propagation of fault rupture to the recording point with a velocity near shear wave velocity results in a peak with a large amplitude and short period in the beginning of velocity record. Generally, estimation methods of structures capacity and ductility distribution along the height of the structure in this type of motions are different from structures experiencing far field earthquakes. In this paper, nonlinear response of tall buildings is investigated under near field earthquakes. The Influence of variations in pulse period on the performance of the structures is studied. Also, capacity of the structure is compared with the results obtained from nonlinear static analysis using conventional load patterns.Velocity response spectrum of these records has several peaks. The period of these peak points is almost equal to pulse period of near-field records. After designing 10, 20, 30 and 40 story buildings according to UBC97 considering near-field parameters, more than 200 nonlinear analysis using Opensees software were performed .The following conclusions are obtained : 1-Increase in story level decreases strength and stiffness, however 30 and 40 story buildings showed close strength and stiffness. 2-Contrary to far-field earthquakes, structural capacity obtained from nonlinear dynamic analysis is higher than nonlinear static analysis. 3-In near-field earthquakes, when a structure has a period greater than pulse period, it experiences large displacements and yields in upper stories due to wave propagation phenomena, then ductility demands immigrates to lower stories. Lower stories should have higher strength and stiffness in order to provide nearly uniform ductility along the building height, in near-field earthquakes. Number of stories requiring modification increases with increase in period of structure

### RESPONSE ANALYSES CONSIDERING STRUCTURAL DETERIORATION OF A RC BUILDING USING EARTHQUAKE RECORDS – ID 1342

*F. Arrecis, Tohoku University, Japan*
*M. Motosaka, Tohoku University, Japan*

Earthquake response correlation analyses of a nine story reinforced concrete building, comprising non-damaging and damaging earthquake levels, are performed focused on the study of the structural capacity and the earthquake demand in energetic terms. Earthquake observation records obtained in the first floor, inside the building, during its 36 years of lifespan, are used as the input ground motions. The correlation of the output time histories of the ninth floor with the records obtained in the same floor is used to verify the correctness of the mathematical models. The initial mathematical model of the building is assembled from capacity curves of individual structural elements, which are mathematically modeled based on construction plans and materials specifications. After each earthquake response analysis, a new mathematical model is assembled accounting for the effects of the structural deterioration caused by each earthquake. Pushover analyses of the first modal shapes of the building are also performed before and after each earthquake response analysis. The energetic capacity of the structure is compared with the energetic demand of different earthquake levels at their occurrence in time. Good correlation is found between structural capacity, observed damage and earthquake demand in energetic terms. The variation of the modal shapes, the fundamental frequencies and the effects of repairs and retrofit works are also observed. These results agree well with the spectral analysis of the records performed by previous researchers. Earthquake response simulations are also performed using the mathematical models of the building. It is observed that the double of the potential strain energy stored at the minimum and maximum response points during the earthquake excitations agree well with the the different earthquake levels' energy input, which keeps quite stable and constant no matter the variation in the fundamental frequencies of the building.

### EVALUATION OF SIMPLIFIED CRITERION OF SOIL-STRUCTURE INTERACTION ANALYSIS – ID 1356

*C. H. Hyun, Korea Institute of Nuclear Safety, Korea, Republic Of*
*J. M. Kim, Yosu National Univ., Korea, Republic Of*
*W. H. Kim, Yosu National Univ., Korea, Republic Of*
*Y. S. Chung, Korea Institute of Nuclear Safety, Korea, Republic Of*
*M. S. Kim, Korea Institute of Nuclear Safety, Korea, Republic Of*

This paper evaluates the simplified criterion for determining whether or not soil-structure interaction (SSI) analysis is required for seismic response analysis of nuclear power plant structures. It is prescribed in ASCE 4-98 that a fixed-base support may be assumed in modeling structures for seismic response analysis when the frequency obtained assuming a rigid structure supported on soil springs representing the soil supporting medium (i.e., the interaction frequency) is more than twice the dominant frequency of a fixed-base flexible structure (i.e., the fixed-base frequency). In this study, the theoretical relationship is investigated between the criterion and the system frequency shift of the soil-structure system relative to the fixed-base frequency. The criterion is also evaluated through simple hand calculations utilizing a simplified single degree-of-freedom model and numerical analysis by SASSI, the computer code for SSI analysis, for several example structures including existing nuclear power plant structures and a model structure for a large-scale seismic test. It is found that the criterion of twice the fixed-base frequency results in 10% system frequency shift (while the one of three times the fixed-base frequency in 5% frequency shift) and in most cases yields a shear wave velocity in a soil medium of greater than 1100m/s, which is a well-known criterion for a rock site in which the fixed-base analysis is allowed. It also can be seen that the soil medium with a shear wave velocity of 1100m/s results in almost 20% system frequency shift in some cases, which may not give conservative results from the fixed-base analysis of a structure.

### EFFECT OF SOIL-STRUCTURE INTERACTION ON INTERSTORY DRIFTS IN A SEVEN STORY RC STRUCTURE – ID 1357

*S. S. Ivanovic, Univ. of Southern California, United States*

Anatomy of interstory drifts in a seven story reinforced concrete structure is investigated, based on multiple earthquake recordings. It is shown that for accurate estimation of relative interstory drifts, the contribution to drifts caused by rocking during soil-structure interaction must be subtracted from the recorded data. Unless this rocking contribution is eliminated prior to fitting the response of structural models to the recorded data erroneous (non conservative) inferences on overall structural properties, and in particular on its actual capacity to withstand strong motion dements, will be inevitable.

### MORE ACCURATE SPECIFICATION OF DESIGN DYNAMIC MODELS OF MULTISTORY BUILDINGS – ID 1361

*M. Nurakhmet, KazNIISSA, Kazakhstan*

Since 2002 dynamic tests of buildings using shakers have been renewed. Majority buildings of two constructive systems

were exposed to tests. Bearing constructions of the first type are the buildings with monolithic ferro-concrete giertless skeleton and with diaphragms of rigidity, as for the second type they have metal skeleton with vertical braces and with monolithic reinforced concrete floors. The obtained results of tests show, that values of experimental and experimental and designed periods of vibrations do not coincide. A discrepancy of designed and experimental values have been influenced by wall fillings and partitions, which rigidity failed to be taken into account throughout designing. Having analyzed results of the periods of fluctuations of high-rises with the various constructive schemes received by experimental and designing methods, it is possible to make the following conclusion. For framed buildings with diaphragms of rigidity and without them, having no wall filling and partitions which influence on total rigidity of a skeleton, design and experimental value of period of vibration approximately coincide. As for buildings where wall filling and partitions (made of brickwork or precast reinforced concrete elements) which rigidity affects total rigidity of skeleton and is not taken into account in design schemes of buildings, the values of experimental and design period of oscillation of buildings do not coincide. As a rule design values of oscillation periods exceed values obtained by experiment Free vibration periods obtained experimentally will allow to define more accurately the design dynamic models as well take into account the influence of non-constructive elements (wall fillings, partitions, etc.) and interaction with foundation of buildings.

## SEISMIC BEHAVIOUR OF REINFORCED CONCRETE STRUCTURAL WALLS UNDER BI-DIRECTIONAL EARTHQUAKE EXCITATION – ID 1366

*N. Ile, INSA-Lyon, France*
*J. M. Reynouard, INSA-Lyon, France*

Within the EC Ecoleader programme shaking table tests on a 5 storey reinforce concrete wall structure have been performed. The structure is composed of two parallel walls linked with a perpendicular one that has openings, and has been sized and detailed following the current design practice in France that induces a small amount of reinforcement. To investigate the behaviour of the specimen, and to assess the validity of the numerical tool, a 3-D refined non-linear analysis was conducted. It is shown that the refined model is able to describe the global behaviour of the structure and qualitatively the distribution of damage at the base of the specimen. Based on the results obtained in this work it appears possible to use these models to investigate numerically the behaviour of a wider variety of configurations that is practically impossible to study experimentally.

## INFLUENCE OF GEOMETRICAL IMPERFECTION ON SEISMIC RESISTANCE OF COOLING TOWER – ID 1369

*R. Pejovic, Faculty of Civil Engineering, Yugoslavia*
*R. Mrdak, Faculty of Civil Engineering, Yugoslavia*
*O. Mijuskovic, Faculty of Civil Engineering, Yugoslavia*

The subject of this paper is research on the seismic response of the reinforced concrete cooling tower, which is performed with pronounced geometrical imperfections in regard to the design state. The subjects of the research were the influence of the geometrical imperfection on dynamic characteristics of the cooling tower and stress strained conditions induced by the effect of earthquakes inside and outside of the imperfection area.

The objective of the research was to quantify the influence of the imperfection in regard to the designed state, to value the influence of the ground on the seismic response and to judge the tower stability under the influence of earthquake for the proper seismic parameters.

The research was done on the cooling tower of the Thermal Power Plant in Pljevlja. The cooling tower was designed from the AB rotational hyperbolic shell, which was supported against 32 pairs of "V" columns along the bottom edge. The tower was 93.20 m high. It was performed with significant deviation in regard to the designed state, in a way that at the spot level 57.50 deviations from the designed radius were 2.76 m (13.7 %).

Although shells are good constructions under influence of earthquake, influence of geometrical imperfections on increase of stress and strains are large. Preformed comparable analysis of rotational hyperbolic shell with geometrical imperfections and designed state of shell shoved that stress and strains in shell with geometrical imperfection are up to five times larger. Also analysis shoved that increase of stress and strains are not limited to area of geometrical imperfection. Analysis also shoved that dynamic response of construction under influence of earthquake is consisted from various frequencies in very wide range which signifies investigation of seismic parameters of micro location of construction.

## MODELING OF REINFORCED CONCRETE STRUCTURES TO ESTIMATE RESIDUAL DISPLACEMENTS – ID 1370

*U. Yazgan, Institute of Structural Engineering, IBK-ETHZ, Switzerland*
*A. Dazio, Institute of Structural Engineering, IBK-ETHZ, Switzerland*

Post-earthquake residual displacements of structures are critical for the usability/reparability of structures which deformed beyond their elastic limits during an earthquake. In light of this fact within the last decade a number of approaches have been proposed to take into account these displacements in the seismic design and performance assessment of structures. The applicability of these approaches strongly relies on the capabilities of available analysis tools to estimate residual displacements. Common modeling approaches, adopted for simulating the seismic response, were mainly proposed for capturing the peak response quantities, like displacements or forces. However, residual displacements are typically more sensitive to the adopted modeling approach compared to maximum response quantities. Current knowledge on the performance of common modeling approaches in terms of estimating the residual displacements is rather scarce. In this study, the influence of major finite-element modeling assumptions on the residual displacement estimates is investigated. The response of a reinforced concrete frame to a set of strong ground motions is simulated with several finite-element modeling approaches. Based on the computed residual displacements, the sensitivity of the results to the adopted temporal and spatial discretization schemes is assessed. Influence of the employed member and material hysteresis models on the global residual displacements is investigated. Furthermore, the sensitivity of residual displacement estimates to the utilized damping models is analyzed. Important issues related to numerical modeling of structures for estimating post-earthquake residual displacements are identified.

## EVALUATION OF THE SEISMIC RESISTANCE OF A PREFABRICATED STRUCTURAL SYSTEM OF LOW WEIGHT – ID 1395

*D. M. Ruiz Valencia, Pontificia Universidad Javeriana, Colombia*

Near of the 75% of the attributed deaths to earthquakes in Colombia, were caused by the collapse of heavy constructions. That 's why it is necessary to study new technological alternatives in structural systems for houses of one story, that are able to support the seismic forces. These new structural systems must be resistant, durable, light and with low costs.

In Colombia, a company has developed a prefabricated system conformed by self-supporting metal panels insulated with polyurethane. Traditionally, this system has been used for partitions. Nevertheless the low weight of the polyurethane and the high resistance of the coworkers-laminae of steel, have suggested that this system could be the structural system of one story houses.

For the previous reasons, a research program was developed in diverse Colombian Universities to evaluate the seismic behavior of the prefabricated system. The experimental program included standard test for evaluate the strength and ductility of the Panels. Several characterization tests of the polyurethane and the steel were performed (shear, tension and compression tests). Several tests were conducted in order to establish the strength of the connections and

the anchorage system. Finally, the panels were tested as structural walls subjected to in plane loads and flexural loads.

Additionally, a three dimensional finite element model of one story house was developed to study the stresses and displacements caused by the seismic loads established in the Colombian code for earthquake design and construction. This stresses and forces were compared with the ones determined experimentally.

In agreement with the results, the structural system would have an excellent behavior to seismic loads due to his low weight and high resistance.

### INELASTIC RESPONSE OF SDOF OSCILLATOR TO COUPLED TILT AND TRANSLATIONAL GROUND MOTION – ID 1418

*P. Ceresa, ROSE School, Italy*
*E. Kalkan, University of California Davis Civil and Env. Eng., United States*
*V. Graizer, California Geological Survey, United States*

Dynamic response of structures subjected to earthquake-induced base excitations are often simplified by ignoring the tilt components of ground motion, however close to the earthquake source, tilting of the ground surface may become significant. Based on strong-motion record at the Pacoima Dam – Upper Left Abutment obtained during the 1994 Northridge earthquake residual tilt reached 3.1° in N45°E direction, while the dynamic tilt remained higher. This study investigates the consequences of neglecting the effects of tilt component in ground motions on elastic and inelastic spectral ordinates. A complete-equation of motion for single-degree-of-freedom oscillator is developed which includes the effects of tilt (as the secondary P-Delta effect) in addition to inertial force effects due to angular and translation accelerations. The expected values of the largest response peaks are computed for the translational and for the tilting excitations to investigate the relative contribution of each forcing function. The coupled tilt and translational ground motion response spectrum (CTT spectrum) is generated considering elastic and inelastic response. The CTT spectrum reflects kinematic characteristics of the ground motion that are not identifiable by the translational ground motion response spectrum alone, therefore emerges as a distinct intensity measure of translational ground motion when it is coupled with significant dynamic tilting of ground surface.

### APPROXIMATE ANALYSIS OF LATERAL-TORSIONAL VIBRATION OF BUILDING STRUCTURES WITH DIFFERENT STOREYS – ID 1423

*G. Tarjan, Budapest University of Technology and Economics, Hungary*
*L. Kollar, Budapest University of Technology and Economics, Hungary*

Approximate vibration analysis may play an important role in the early design stage of building structures when the final dimensions and the locations of the horizontal load-resisting subsystems are not known, and also in their final design for the verification of the more sophisticated finite element models.

One of the most effective approximate methods is the continuum analysis which was applied successfully for determining the periods of vibrations and the earthquake induced base shear forces of building structures. Almost all the previous analyses considered identical storeys along the height of the building which is not a realistic assumption for high rise buildings, which require significantly stronger, and hence stiffer elements at the bottom than at the top.

Our aim in this article is to give a simple continuum approach, which is applicable for lateral-torsional vibration of buildings with different storeys.

The building structure may be braced by an arbitrary combination of shear walls, coupled shear walls, frames, trusses and cores. The arrangement of the horizontal load-resisting subsystems may be symmetrical or asymmetrical. The stiffnesses of the structure may be uniform or may decrease with the height. Masses of the individual storeys are identical, except the mass of the top floor. First and second periods of vibration of lateral-torsional vibration are determined using replacement beam models. The building structure with varying stiffnesses is replaced by a continuous beam with uniform stiffnesses, and its periods of vibration are calculated by approximate formulas given in the literature.

### FLEXURE-SHEAR FIBRE BEAM-COLUMN ELEMENT FOR MODELLING OF STRUCTURES UNDER SEISMIC LOADING – ID 1425

*P. Ceresa, ROSE School, Italy*
*L. Petrini, Politecnico di Milano, Italy*
*R. Pinho, Università degli Studi di Pavia, Italy*

Whilst currently existing modelling approaches of RC behaviour allow a reasonably accurate prediction of flexural response, the determination of shear strength and deformation response characteristics is still a field that is in very much need of further development. In particular, the accurate simulation of the behaviour of RC structures subjected to strong ground motion is still a challenging and opened problem. Accordingly, while various models for predicting shear response under monotonic loading have been successfully proposed up to now, very few are the reported models that have demonstrated successful results under cyclic loading.

The modified compression field theory (MCFT), proposed by Vecchio and Collins (1986), stands out as one of those models that seems to be able of accurately predicting the shear strength of both reinforced- and prestressed concrete members subjected to monotonic loads. In addition, during the last twenty years, this theory has been further developed and upgraded, with the aim of capturing the force-deformation response of RC members under reversed loading. The procedure exhibited very good accuracy when compared to experimental test results on panels and shear walls.

The above seems to indicate that the MCFT approach constitutes an interesting and pertinent model for earthquake engineering simulations. The proposed research work therefore deals with the application of the compression field theory in the analysis of RC frame structures subjected to seismic action. This requires, for reasons of computation efficiency, an innovative implementation in beam-column element types, as opposed to shell or solid elements. In addition, and so as to warrant adequate accuracy, with relatively simple calibration efforts, when structures are pushed well into their nonlinear response range, a diffused plasticity approach (multi-fibre beam element) has been equally adopted, using MCFT as constitutive model.

### REALISTIC MODELLING OF THE DEFORMATION BEHAVIOUR OF BOX-GIRDER BRIDGES – ID 1446

*M. Dr. Empelmann, HOCHTIEF Construction AG, Germany*
*M. Girmscheid, HOCHTIEF Construction AG, Germany*
*D. Dr. Nowak, HOCHTIEF Construction AG, Germany*

For the modelling and the seismic analysis of bridges different methods of analysis are available and well known by earthquake engineers. In conjunction with today's powerful computer software and hardware those methods of analysis give the designers the opportunity to realistically model the deformation and response behaviour of bridges under seismic actions.

Recent design works on major bridge projects show that especially in case of irregular box-girder bridges, with a considerable stiffness difference between adjacent piers, such realistic modelling is of great importance for the determination of the seismic actions. For such bridges the vibration behaviour in transverse direction is characterised by out-of-phase movements of adjacent piers resulting in a twist of the box-girders. The resulting torsion demand in the box-girder is imposed by relative deformations between adjacent piers. Its size and magnitude is a function of the stiffness of the whole structural system, and in particular the torque-twist-relationship of the box-girder including both, St. Venant Torsion and Torsional Distortion. Due to construction reasons box girders are often designed without any classic diaphragm and with a thickened end section only. In this case, the influence of Torsional Distortion is significant and cannot be ignored. In technical literature the consideration of the actual deformation behaviour of irregular box-girder bridges includ-

ing both St. Venant Torsion and Torsional Distortion, is addressed only rarely. The paper gives an overview on the mechanical relationships and the different calculation methods. Based on examples from recent construction projects parameter studies were performed on box-girder systems using different methods of analysis, finally leading to a recommendation of a simple and realistic design approach.

The full and realistic consideration of the torsional stiffness results into a better determination of the seismic actions and the reference to construction projects shows that such consideration is essential for an economic design.

### MICRO-MESO-MACRO SCALE MODELLING AND ANALYSIS OF THE CAMUS I RC SHEAR WALL – ID 1478

*D. Coronelli, Dept. of Struct. Engng., Politecnico di Milano, Italy*
*L. Martinelli, Dept. of Struct. Engng., Politecnico di Milano, Italy*
*P. Martinelli, Dept. of Struct. Engng., Politecnico di Milano, Italy*
*M. G. Mulas, Dept. of Struct. Engng., Politecnico di Milano, Italy*

The focus of the work is on the structural modelling of one of the two 5-story, 1/3rd scale, R/C shear walls tested on a shaking table for the CAMUS Program, and on the analysis issues related to the reproduction of the experimental results. The wall was designed according to the French code PS92 and is representative of existing structures not fully complying with the requirements of recent seismic codes. The wall was subjected to two different accelerograms, representative of near and far field earthquakes respectively, each of them scaled to two different PGAs; a fifth accelerogram caused the failure of the wall. Three different levels of refinements have been adopted in the structural discretization of the wall, namely the micro-scale of the finite element method, the meso-scale of a fibre model for 1D elements, and the macro-scale of a beam spread-plasticity element. The micro and meso-scales are able to follow at local level the material constitutive relations in terms of stress-strain, and differ mainly for the richness of the kinematic field, quite general for the micro scale and tied to geometric hypotheses on the cross-section behaviour for the meso-scale (Timoshenko beam model). The macro scale tracks the material behaviour in terms of a sectional property, the moment-curvature relation, and relies on a flexibility approach, with a less rich kinematic field. To reproduce the experimental results two different numerical approaches of analysis have been adopted: a push-over monotonic analysis within a displacement-based assessment and a dynamic step-by-step analysis. The pushover analysis has been performed at the micro and meso scales; the meso and macro-scales have been adopted for the dynamic analyses. The comparison of numerical and experimental results provides useful indications about the modelling approaches to be adopted in predicting the non linear seismic response through simplified and exact procedures.

### CAPACITY SPECTRUM METHOD CONSIDERING SOIL-STRUCTURE INTERACTION EFFECTS – ID 1479

*M. R. Bayat, Sharif University of Technology, Iran (Islamic Republic Of)*
*M. A. Ghannad, Sharif University of Technology, Iran (Islamic Republic Of)*

The soil affects the structural response in two ways, through the change in the free-field motion (usually known as the site effect) and due to Soil-Structure Interaction (SSI). The site effect has been included in the seismic codes from the most beginning. However, the SSI effect has not attracted much attention. The most significant intervention in this regard has been the 1978 inclusion of SSI in the tentative provisions of ATC3-06, which is based on the results of studies on elastic response of soil-structure systems. From another point of view, as the current seismic design philosophy is based on nonlinear behavior of buildings during moderate and strong earthquakes, there is a need to investigate the effect of soil on nonlinear response of buildings. In this research, a procedure is proposed to incorporate the SSI effects into Capacity Spectrum Method of ATC-40, a common use procedure to determine the structural performance point, which is based on equivalent linearization of nonlinear structural response. The accuracy of the proposed procedure with respect to the exact results of nonlinear time history analysis of the Soil-Structure system has been examined through an extensive parametric study in different ranges of the structural and soil parameters. The results show that the accuracy of the proposed procedure is in the acceptable range and it can well predict the actual behavior of the Soil-Structure system in many ranges. Furthermore, the main effects of the soil flexibility on the performance of buildings are obtained by comparing the ductility demand of the Soil-Structure models using the proposed procedure to that of the fixed-base structure. The results reveal that the base fixity assumption is not always conservative and there could be many fixed-base systems that their ductility demand would increase by adding the soil beneath their base.

### THE EFFECT OF HIGHER MODES IN DYNAMIC BEHAVIOUR OF TALL BUILDINGS – ID 1519

*A. Gandomzadeh, Amir Kabir University of Technology, Iran (Islamic Republic Of)*
*F. Khoshnoudian, Amir Kabir University of Technology, Iran (Islamic Republic Of)*

One of the main advantages of the modal analysis method is that it is not necessary to calculate all vibration modes. In order to optimize the calculations, the initial selection of a reduced number of modes by seismic codes for dynamic analysis has been defined. In some cases this recommended number of modes may provide large errors in structural response. This article has studied the influence of higher modes in order to determine the number of required modes in spectral analysis to obtain desirable error. The studies include number of floors, the main period of structure, the period of soil and also the spectrum used in spectral analysis. Then the Iranian practice code (2800) has been verified for spectral dynamic analysis. For this purpose 5 to 45 stories buildings have been considered and designed according to Iranian code. The effect of some parameters has been studied such as type of structural system, the relative stiffness, irregularity in plan and irregular distribution of mass in height. Finally some formulas has been suggested for determining the minimum number of required modes in order to obtain less than 5% and 10% error in structure response. Our results show the validation of suggested formulas.

### SEISMIC BEHAVIOR OF VERTICALLY HYBRID BUILDINGS – ID 1520

*A. Kheyroddin, Semnan University, Iran (Islamic Republic Of)*
*A. Hemmati, Semnan University, Iran (Islamic Republic Of)*

Hybrid buildings, which consist of two different structural systems in height, don't show good seismic response. Use of reinforced concrete frames for lower stories and steel frames for upper stories is an example of hybrid buildings and Under the earthquake loads, steel frames may slip on lower concrete parts. In this paper 5, 10 and 15 story buildings that have R.C frames with shear walls in lower stories and steel frames with bracings in upper stories are investigated. The linear behavior of these buildings (lateral displacement, internal forces in transition level,...) is investigated with ETABS 2000 software. Moreover Push-over analysis is done and capacity diagrams are presented too. Also nonlinear behavior of these buildings under the earthquake loads (ductility, ultimate lateral displacement, ultimate strength, arrangement and position of plastic hinges, hystersis loop diagrams,...) is investigated with RAM PERFORM-3D software according to FEMA-273 and FEMA-356. Analytical results show that with using "TRANSITION STORY" between two different parts of hybrid structures, the seismic behavior of these buildings is improved. Transition story, which is located in the transition level, is a composite (steel-concrete ) story with composite columns, Shear walls and steel bracings. Number of transition floors is dependent on total height of hybrid

building and applied loads. More details about this story presented in this paper. The best position of this story is in one-third of the height of hybrid building from above. Moreover with using transition story in hybrid structures, axial and shear forces at transition level decrease and ductility increases.

KEY WORDS: Hybrid buildings, Linear behavior, Nonlinear behavior, Transition story, Ductility.

### SEISMIC BEHAVIOR OF PRECAST INDUSTRIAL BUILDINGS – ID 1564

*M. Kramar, IKPIR, Slovenia*
*M. Fischinger, IKPIR, Slovenia*

Precast RC industrial buildings represent a frequently used structural system all over Europe. There has been certain mistrust regarding the use of such systems in seismic areas. However there has never been enough research evidence to estimate seismic vulnerability of such systems. This has been reflected in EC8 requirements, which differ a lot from one version of the code to the other. Therefore a large research project has been initiated to estimate seismic vulnerability of precast industrial buildings and to provide background of EC8 requirements.

Experimental tests have been performed within the PRECAST EC8 5th Framework project (coordinated by Politecnico di Milano). This paper refers predominantly to analytical simulation of the part of the tests performed at ELSA European Laboratory for Structural Assessment in Ispra, where a series of pseudo-dynamic and cyclic tests of two full-scaled prototypes, representative for Italy and Slovenia as well as some other Central European countries have been performed. University of Ljubljana provided analytical support, documented in this paper. Numerical analyses were made with OpenSees software, using standard macro elements. Refinements of the elements were made on the basis of the experimental results and refined FE analyses. Seismic vulnerability of the analyzed systems was estimated using simplified probabilistic methods and some recommendations for EC8 were formulated.

### FRAGILITY ANALYSIS OF FLEXIBLE BASE BUILDINGS – ID 1567

*T. Naqvi, Aligarh muslim university, India*
*T. K. Datta, Indian Institute of Technology, India*
*G. V. Ramana, Indian Institute of Technology, India*

A simplified fragility analysis of flexible base building frames is presented which can be easily adopted in practice. The fragility analysis a band limited white noise and a white band response spectrum as inputs to the bedrock level. The corresponding free field response spectrums are used for obtaining the seismic forces on the frame. In obtaining the free field response spectrum the effect of the soil layer is duly taken into consideration by considering both linear and nonlinear properties of the soil. An equivalent lateral load analysis is performed to find out the seismic response of the structure at various sections. The probability of failure at a section is obtained by using plastic analysis and the first order second moment theory of reliability. For determining the probability of failure, the uncertainties included in the study are those of modeling of the system, inelastic action, concentration of hinges, earthquake input, base flexibility etc. The sensitivity of the probability of failure to the variation of some important parameters is conducted through a numerical study on a twelve-storey steel building frame. The results of the study indicate that (i) the consideration of base flexibility and nonlinearity of the soil have considerable effect on the probability of failure of the frame; and (ii) in the absence of reasonable response spectrum at the bedrock level, the assumption of white noise at the bedrock level provides conservative estimate of probability of failure.

Key words: Seismic reliability, fragility analysis, risk consistent response spectrum and flexible base building frame.

### FRAGILITY ANALYSIS OF DETERIORATED REINFORCED CONCRETE BEAM IN NPP FACILITIES – ID 1576

*M. Moosoo Kim, KINS, Korea, Republic Of*
*M. Myungkue Lee, Jeonju University, Korea, Republic Of*
*C. Yunseok Chung, KINS, Korea, Republic Of*

A better understanding of the effect of aging degradation on structures is needed to ensure that the current licensing basis(CLB) is maintained under all loading conditions. Therefore, it is reviewed in this paper how the age-related degradation affects on the structural response of concrete elements and what is taken into account in margin assessment considering degradation. Fragility curves of typical beam in NPPs are developed based on the degree of deterioration of the member considered and compared to investigate its influence on ultimate strength of the members. The models were simulated by Latin Hyper-Cube (LHC) method considering various aging-related deterioration of RC beam. Fragility curves under various condition subjected to static load are compared. It is found that the 20% loss of top and bottom steel lower 15% of the undegraded beam strength. For the beam models, the fragilities considering the horizontal seismic horizontal attenuation are calculated and compared by FEM analysis

### NONLINEAR STATIC AND NONLINEAR DYNAMIC ANALYSES IN THE ESTIMATION OF THE MAXIMUM RESPONSES – ID 1578

*P. Tehrani, University of Tehran, Iran (Islamic Republic Of)*

In this study, the nonlinear static and nonlinear dynamic procedures in the determination of maximum displacements of an existing 9 story steel structure retrofitted with different methods have been compared. These methods include the use of the EBF systems; RC Shear Walls and use of Passive energy dissipators such as metallic TADAS dampers, viscous dampers, viscoelastic dampers and friction dampers. Each damping system has been modeled for several damping ratios and damper properties. In nonlinear dynamic procedure, the response of the structure to seven scaled earthquake records matched to the design spectrum has been obtained and the average value of the responses is used for comparison. At the same time in nonlinear static procedure, the maximum displacement of the structure in two different load distribution patterns namely uniform and spectrum patterns have been obtained. The results demonstrate that nonlinear static procedure determines the maximum displacement of the structure conservatively. Particularly with the use of the Viscous Dampers in the structure difference between the results, will become more pronounced. In addition, it seems that this difference increases when the structure becomes more flexible.

### DYNAMIC STRUCTURE-TO-STRUCTURE INTERACTIONS OF THREE BUILDINGS – ID 1605

*N. Deng, Bechtel National Inc., United States*
*F. Ostadan, Bechtel National Inc., United States*

This paper presents the analytical results of dynamic structure-to-structure interactions for a three building assembly – A major industry processing building (568 ft. by 238 ft.) and its control and auxiliary buildings. All analyses were performed for a wide range of soil profiles and in all three directions. The results show that the structure-to-structure interaction effects have major impact on the behavior of the smaller buildings such that the results from the combined model in the most cases are the controlling results. The magnitude and manners of the structure-to-structure interaction are also discussed.

### STRUCTURAL ANALYSIS AND SEISMIC STRENGTHENING OF EXISTING AL- SHOUNA HOSPITAL IN JORDAN (STUDY CASE) – ID 1652

*M. Jahmani, Ministry Of Public Works And Housing, Jordan*
*J. Qtaishat, Ministry Of Public Works And Housing, Jordan*

The existing Al–Shouna Hospital is located near Dead Sea which is the lowest point in the world and lies in seismic zone "3" according to seismic zone map of Jordan. The structural system of the hospital consists of reinforced concrete ordinary moment resisting frames (O.M.R.F.)without shear walls.

The scope of work consists of three stages, first, site inspection, second, structural analysis and verification of results, and third, seismic strengthening of structure using static force procedure, since the hospital has regular structure with height not exceeding (7m). In general terms, response of regular structures to dynamic forces is dominated by the first mode of vibration, therefore, dynamic analysis is not adopted in this scheme, while equivalent static procedure will be performed.

The structural analysis of the existing hospital shows that it cannot resist the expected seismic forces for each frame in both directions and needs strengthening of the existing frames by adding new reinforced concrete shear walls, which is properly, the best method of strengthening the existing hospital and improving seismic performance.

The proposed reinforced concrete walls are generally cast-in–situ. Adequate connections of the new shear walls with slabs (diaphragms) and foundation are provided according to Jordanian code requirements.

## FINITE ELEMENT ANALYSIS OF FIXING THE STEEL PLATE WITH BRACES ON BEHAVIOR OF RETROFITTED RC BEAMS – ID 1717

*A. Guray, Yildiz Technical University, Turkey*
*S. Filiz, Yildiz Technical University, Turkey*
*E. Ibrahim, Yildiz Technical University, Turkey*

Almost all researchers studying in this field agree on the significant contribution of using epoxy-bonded continuous horizontal steel plates on load carrying capacity of reinforced concrete (RC) beams with rectangular cross-section. However, there is not enough data available on the effect of O-shape jacket at the end of flexural steel plates (fixing the steel plate with braces) and there is no consensus on the contribution I-shape jacket to this type of beams within the limited available data. In this study; the use of end anchorage technique such as I-shape jacket is investigated and having the different distance of fixing the steel plate with braces from mid-span are evaluated. Using the analytical model "Drucker-Prager", which are proven by the experimental studies and changing the distance of fixing the steel plate with braces from mid-span, analytical solutions are provided; then the load-deflection curves are compared and some comments are made on.

## NEW SEISMIC ISOLATION SYSTEM FOR BUILDINGS – ID 1761

*D. Ristic, IZIIS, Macedonia*

Presented in this paper is a newly developed new general seismic isolation system for buildings (BL2-GSI System) with advanced performances based on full seismic energy control. This has been achieved by integration of the advantages of the seismic isolation system and the new concept of multi-level seismic energy absorption. This new technology with qualitatively improved seismic protection of buildings is based on application of own patent developed in the course of the realization of the long-term pilot-innovative project entitled "Seismically Safe Cities of the Future". The BL2-GSI system enables application of a wide range of seismic isolators. In addition, the proposed new multi-level seismic energy absorber has extraordinary features as to adapting its behavior to the actual seismic intensity level. If there is no earthquake excitation, the energy absorber is not active and the behavior of the structure is the same as the behavior of any traditionally constructed building. If an earthquake occurs with a relatively low to moderate intensity, the seismic energy absorber reacts with adequately increased energy dissipation level. This enables complete protection of the structure. Finally, in case of the most severe earthquake, the seismic energy absorber reacts with its full capacity for energy dissipation. The required capacity for seismic energy dissipation has been defined by advanced design analyses in the theoretical part of the investigations. The multi-level response of the BL2-GSI system in compliance with the input seismic energy provides complete seismic protection of structures, even under the strongest earthquake excitations. At present, research activities are continued in the frame of a 3-year scientific project and will be focused on practical application of the invented BL2-GSI System.

## CASES OF STUDIES ON THE SEISMIC VULNERABILITY ASSESSMENT OF EXISTING BUILDINGS IN SWITZERLAND – ID 1830

*Y. Belmouden, EPFL, Switzerland*

This work presents preliminary results on the evaluation of the seismic capacity of existing buildings in Switzerland. Comparative analyses of regular reinforced concrete shear wall and two-axes asymmetric-plan unreinforced masonry (URM) existing buildings are presented. The latter is modeled as an equivalent frame model. The conventional multimodal force-based 'Push-Over' method is used. Capacity diagrams are carried out by the Drain3DX software using three dimensional fiber beam element model. The numerical results are compared with simplified analytical methods and with existing models such as Risk-UE and Hazus. Both torsional effect and higher modes of vibration are taken into account trough modified load patterns in both principal directions of the buildings. Preliminary conclusions regarding the applicability of the existing capacity diagrams proposed by Hazus and Risk-UE are drawn and discussed. The numerical results show that both Hazus and Risk-UE capacity diagrams are valid for seismic vulnerability assessment of RC shear wall structures. For the number of story sub-class, the capacity diagram given by Risk-UE doesn't correspond to the numerical curve of the considered building while Hazus capacity diagram does. The sub-classification in terms of number of stories should be carefully calibrated. More investigations are necessary for an objective determination of the ultimate top-displacement. For the URM structure, the fiber model did not consider both rocking and sliding behavior. So the comparison of the Risk-UE capacity diagrams show discrepancies in terms of maximal strength and displacement. However, the capacity diagrams with or without torsion effect describe different behaviors in both weak and strong direction for each mode of vibration. This study supports the development of more complex models with Finite Element / Discrete Element combination and to analyse a large number of typical buildings. A parametric study on the use of the multimodal Push-Over method on torsionally unbalanced buildings is in progress

## SHEAR STRENGTH OF REINFORCED CONCRETE SHORT BEAMS WITH STIRRUPS – ID 1900

*A. Guray, Yildiz Technical University, Turkey*

In the design of reinforced concrete (RC) short beams, the arch action on the shear strength becomes more significant as the a/d ratio decreases. In this study; new design expressions are proposed, based on Arslan's cracking shear strength of RC slender beam, taking into account the arch action for the design of RC short beams with stirrups. Proposed equations are verified by comparisons to extensive sets of experimental data from the literature, which have been obtained on short beams with various strengths of concrete, stirrups nominal strength, shear span to depth ratio and geometrical sizes. The results are compared with those predicted by the ACI 318 Building Code and Turkish Code. The proposed equations show good agreement with regard to existing test results, whereas the ACI Building Code and Turkish Code equation predict shear strength of normal strength concrete beams excessively conservative.

## AN EVALUATION METHOD FOR PASSIVE CONTROL SYSTEMS SIMULATED BY MAXWELL DAMPING MODELS – ID 2040

*H. Ishigaki, Nihon University, Japan*

This paper presents a performance evaluation method for passive control systems with viscous damper expressed by Maxwell models. It is very difficult to estimate simply the maximum seismic response value by cause of the system property of frequency-dependency. In this study, eigen value problems with complex numbers are analyzed for the system, so as to investigate the dynamic characteristics. Generally, a single mass-spring system with Maxwell model has three degrees of freedom. That is, the three eigen values are derived, in which the two are conjugate complex numbers " A " and " A* ", and the other is real number " B ". And the multiplication between the conjugate complex numbers makes the square value of natural circular frequency " F " and the sum of them derives the value of " -2hF ", in which the variable " h " means the viscous damping factor. For convenient, the eigen value of real number is replaced by the value " h'F ". The result shows that Maxwell model and Voigt model have the same natural period and viscous damping factor for the case that the value "h' " becomes bigger than unity. In addition to this, an empirical formula with those parameters " h" , " F " and " h' " is proposed in order to estimate the maximum seismic response values of the system.

### PUSHOVER ANALYSES: SEISMIC RESPONSE EVALUATION OF AN INFILLED FOUR STOREY R.C. BUILDING DAMAGED BY THE 2002 EARTHQUAKE IN MOLISE (ITALY) – ID 2056

*T. Albanesi, University of Roma Tre, Italy*
*E. Candigliota, University of Chieti-Pescara, Italy*

Pushover analyses are today very popular as simple and fast tools to assess seismic response of buildings but are still prone to criticisms. Many approaches are proposed in literature and some of which are included in Codes too. Both non-adaptive and adaptive pushover analyses in uni-modal and multi-modal forms are applied for the seismic response evaluation of an infilled r.c. frame building in Bonefro (Molise, south-Italy), damaged by seismic events on October 31 and November 1, 2002. The building is a four storey r.c. frame structure with rectangular plan, tile-lintel floors and staircase in the middle of the long side. The infill panels are double disconnected walls in bricks with high hollow percentage. The distribution of the panels is quite irregular: they are often not aligned to the r.c. frames and at the ground floor few bays are infilled. The structure, built at the beginning of the 80's, is placed in a zone that wasn't seismic classified neither when the building was built nor when the earthquake occurred. The building was seriously damaged by the seismic events: the ground floor suffered heavy damages while the other floors seem to be in good conditions. The infill panels present diagonal or cross cracks and, sometimes, out-plan upsetting of the external wall, some beam-column joints show significant damages with cover expulsion, stirrups opening and longitudinal bar buckling. The 3D mathematical model adopted for the building aim to be an example of simplified model to be used in current design professional practice. The main aim is to assess the effectiveness of pushover analyses in forecasting the "real" seismic response of the building: the damage distribution, the damage level and the failure mechanism, evaluated via non-linear static analyses, were compared against the real damage scenario.

## ES 3f: Structural Engineering - Masonry and Timber

Level-1

### THE INFLUENCE OF VERTICAL MORTAR JOINTS ON THE SEISMIC STRENGTH OF UNREINFORCED BRICK WALLS – ID 28

*M. R. Maheri, Shiraz University, Iran (Islamic Republic Of)*
*M. A. Najafgholipour, Shiraz University, Iran (Islamic Republic Of)*

The masonry shear walls are the main seismic load-resisting elements in unreinforced masonry buildings. The in-plane shear resistance and the out-of-plane bending capacity of the walls are their main lines of defense against the earthquake loads. The shear and bending capacities of the brick walls are, on the other hand, dependant on the ability of the horizontal and vertical mortar joints to transfer the loads through the brick units. When constructing the brick walls, in a number of Middle Eastern and East European countries, it is common practice to leave the vertical joints between the brick units without any mortar. This is done either for architectural purposes or more often, to increase the speed of construction. This practice, though may not significantly affect the vertical load-bearing capacity of the walls, it drastically reduces both the in-plane shear and out-of-plane bending capacities of the walls and consequently the seismic strength of the building. In assessing the shear and bending capacities of a brick wall for seismic evaluation and retrofitting of the building, it is necessary that the level to which the wall strength is reduced due to this omission is well established. No research is reported in the literature aimed at directly determining the level to which the omission of the vertical mortar joints affects the strength of the wall.

In the proposed paper, results of a number of tests conducted on small scale brick walls, with vertical mortar joints and without vertical mortar joints, will be presented and compared to obtain some insight into the effects of vertical mortar joints on the strength of the wall. The experimental work will then be substantiated by a series of numerical studies on the effects of vertical joints in the seismic strength capacities of small scale and full scale brick walls.

### DESIGN OF MASONRY BUILDINGS IN SEISMIC REGIONS OF REPUBLIC OF MOLDOVA – ID 85

*A. Zolotcov, Moldova, Republic Of*

Republic of Moldova is located in a seismic area with the seismicity between 6 and 9 degrees on MSK scale. The epicenter of the earthquakes is in the Carpathian Mountains, in the Romanian region of Vrancea.

During USSR the specialists from the Moldovan Design Institutes were using Soviet construction codes for design of masonry buildings, such as SNiP II-22-81 «Stone Constructions and Reinforced Stone Constructions" and SNiP II-7-81 «Seismic Building Code».

The buildings and edifices that were designed and built at that time according to the above mentioned codes were hit by the Carpathian earthquakes from 1977, 1986 and 1990 without sustaining any serious degradations.

Currently, the design of the stonework buildings is based on Moldovan codes NCM F.03.02 "Design and calculation of the masonry structures". These codes were elaborated by Moldovan scientists who conducted various experimental and theoretical studies.

Based on these fundamental studies, the Moldovan antiseismic engineers developed new constructive solutions aimed to increase the height of stonework walls buildings to up to 9 stories. Moldova is the only former soviet country that designs and builds stonework buildings with such a height in seismic regions.

This report reveals the design requirements for the foundations (footing), the walls and the seismic belts of masonry for buildings with up to 9 stories located in Moldovan seismic areas. These regions have a seismicity range between 6 and 9 degrees on MSK scale. The author believes that these requirements could be successfully applied in other seismic regions in Europe.

### SEISMIC BEHAVIOUR OF IRREGULAR MASONRY WALLS – ID 86

*N. Augenti, Università di Napoli Federico II, Italy*

If the openings of a masonry building wall are not aligned, the wall is called irregular. The stagger of the openings may be vertical or horizontal. Both the irregularity kinds strongly influence the seismic behaviour of masonry walls, as clearly shown by the damages of violent earthquakes. With regard to structural analysis of masonry buildings subjected to seismic actions, the author set up, few years ago, a calculus method through macro-elements particularly simple to be applied for professional use. In the present

paper the way the irregularities affect the wall seismic behaviour is examined. In particular, different modelling approaches for irregular walls (both vertically and horizontally) are illustrated and the gained results compared.

### SEISMIC BEHAVIOUR OF SANTA MARIA OF BELEM CHURCH – ID 90

*J. A. Roque, Institute Polytechnic of Bragança, Portugal*
*D. Oliveira, University of Minho, Portugal*
*P. B. Lourenço, University of Minho, Portugal*

The paper presents an integrated methodology for seismic behaviour characterization of ancient masonry structures of significant heritage importance, including possible strengthening measures towards the mitigation of the seismic risk. The proposed methodology is here applied to an outstanding case study composed by the Santa Maria of Belém Church of the Monastery of Jerónimos, in Lisbon, Portugal, dating from the 16th century and being one of the most emblematic Portuguese monuments. The methodology includes the following main steps: seismic action characterization, from the earthquake source areas identification to artificial generation of acceleration time histories, using specific theoretical models and including superficial site-effects; simple numerical modelling for a preliminary knowledge on the structural behaviour; definition and installation of static and dynamic monitoring systems aiming at a better understanding of the static and dynamic behaviour; experimental mechanical characterization of materials and structural elements; development of advanced numerical models including the necessary calibration against experimental relevant data; non-linear dynamic analysis of the structure for different earthquakes and discussion of results; selection of representative structural parameters for damage evaluation; proposal of a set of recommendations for structural conservation and/or rehabilitation purposes.

### PERFORMANCE OF URM WALLS STRENGTHENED WITH CFRP UNDER HORIZONTAL CYCLIC LOADING – ID 299

*C. To-Nan, National Cheng-Kung University, Taiwan*

In Taiwan lots of historic buildings are constructed by unreinforced masonry. For a better earthquake safety of these historic buildings, these walls usually need to be strengthened. In this study , the structural performance of URM walls strengthened with CFRP is investigated . There are nine 1B wall specimens with 164cm in width and 157cm in height strengthened with CFRP strip along the two wall diagonal and these wall boundaries are tested under horizontally cyclic loading which are controlled by relative displacement angle. From the test , followings are observed:(1) The cracks of strengthened walls are found along the lower edge of the diagonal strengthened area and the CFRP along another wall diagonal are sheared off .This mode is different from that of URM walls. (2) The maximum resisting load of the specimen strengthened after damage is close to that of the specimen strengthened prior to the damage. However , the ultimate relative displacement angle of specimens strengthened prior to the damage is much larger. (3) The specimen strengthened with wider CFRP strip provides higher relative displacement angle and better energy-absorption. (4) The obtained strengthening benefit of lime-cement mortar specimens are more visible than that of cement mortar specimens. The result obtained in this investigation give the bases for practical the conservation design or structure assessment of existing masonry historic building.

Keyword: URM , Brick walls , Strengthen , FRP

### STUDY ON SEISMIC RESPONSES OF THE YINGXIAN WOODEN TOWER IN SHANXI PROVINCE – ID 375

*Y. He, Tokyo Metropolitan Universit, Japan*
*T. Iwatate, Tokyo Metropolitan Universit, Japan*
*X. R. Ge, Shanghai Jiaotong University, China*

The YingXian Wooden Tower in Bukyu-Temple of ShanXi province, China built in 1056A.D.is one of the most oldest existing wooden tower(an important cultural asset) in China. It was suffered many damages (incline of the columns, settlements ,and together with the weekend materials of structure, escape from collapse ) due to the past earthquakes and the ravages of wars, . It is faced to repair and reinforcement, right now. This paper shows the dynamic characteristics of the tower and the surrounding ground by the microtremor measurements and the numerical analyses. The main results are obtained as follows. (1) Microtremor measurements on the ground and the tower Microtremor measurements were conducted at the 40 points on the surface ground and 37 points each floor (ground, 1st, 2nd, 3rd, 4th, and 5th, floors) of the tower through 24 hours. The predominant frequencies of the ground were obtained , 2.6Hz 3.0Hz,for horizontal NS-direction, 2.6Hz 3.3Hz for horizontal EW-direction, and 2.5Hz 3.5Hz for vertical direction, respectively. The natural frequencies and vibration modes of the tower were obtained, 1st:0.68Hz, 2nd:1.85Hz, and 3rd:3.13Hz. (2) Seismic response analysis of the tower The dynamic characteristics of the wooden tower were investigated numerically by the finite element method. The tower was modeled by 3-dimmensinal beam elements with mortise and joint-bucket arches. The natural frequencies, vibration modes of the tower-model agree well with the observed ones. The seismic response analyses were conducted using this model and the observed earthquake at Zushi (Japan) with 3 different amplitudes, and estimated the acceleration, displacement responses structure and bending moment ,stresses of the timber of structure . From these data, the seismic stability of the ancient tower was evaluated. These results will be valuable for the maintenance and restoration of the ancient wooden structure

### ANALYSIS OF THE DEGREE OF INFLUENCE OF DISSIPATIVE AND NON-LINEAR ELASTIC PROPERTIES OF STRUCTURAL MEMBERS OF FRAME TYPE TIMBER BUILDINGS ON THEIR SEISMIC STABILITY – ID 390

*T. Belash, Petersburg Transport University, Russian Federation*
*J. Ivanova, Petersburg Transport University, Russian Federation*

This report contains the results of experimental and calculation-theoretical investigations of the frame type building operation. The experimental investigations have been carried out on large-scale models with the account of various structural solutions of joint connections. The calculations have been performed for seismic actions to be specified by instrumental records of accelerograms corresponding to real earthquakes. Three calculation model versions have been considered (basic; with the availability of a flexible bond in the base; with the availability of flexible joints in floorings and load-bearing framework uprights). The calculations have taken account of non-linear elastic and dissipative characteristics of building elements. As a result of investigations, a method has been elaborated for assessing the seismic stability of frame type timber buildings with the account of non-linear elastic and dissipative properties of the element material for a broad class of seismic actions. It has been determined that in order to reduce seismic inertial loads with seismic actions on the wooden constructions of a frame type building, it is necessary to take into account the concurrent reduction of the whole rigidity of its load-bearing structures, with their deformation ability being provided. The parameters of elastic elements have been determined, which allow to reduce by several times the seismic load level on the timber building type being under investigation.

### COMPARISON OF SEISMIC CAPACITY OF URM BUILDINGS USING DIFFERENT GUIDELINES AND EXPERIMENTAL RESULTS – ID 441

*F. Alemi, IIEES, Iran (Islamic Republic Of)*
*F. Nateghi, IIEES, Iran (Islamic Republic Of)*

After recent earthquake of Bam in southern province of Kerman in Iran in 2003, and very poor behavior of the existing

URM buildings during this massive earthquake, a general program was lunched to investigate and assess the capacity and vulnerability of these buildings against seismic forces.

In literature three methods have been used for determining the seismic capacity of URM buildings namely; a)sophisticated approach using finite element and discrete element methods, b)simplified approach using equivalent frame and story mechanism methods and c)traditional approach by using calculations of capacity resulted from building codes and guidelines. It worth noting that all of the above mentioned methods, due to the uncertainties in material properties are considered to be approximate analytical approaches. Therefore, for simplicity, the latest code and standards approach is used more often.

However in doing so, results obtained by each code differ from each other, sometimes by far. Comparison of resulted capacity byFEMA-178 versus UCBC-97 results in three times higher values for different formulas. In this study, guidelines provided by FEMA-178, UCBC-97, FEMA-306 and experimental results obtained by tests conducted in Iran, Italy, Canada and USA are compared. The results of this comparison indicate that in order to correlate the experimental and analytical results, one should apply some correction factors to each of the formulas provided by these guidelines. This paper will discuss the approaches, comparison and suggested correction factors each case separately. ns provided by the above guidelines.

## MODELING SEISMIC PERFORMANCE OF RESIDENTIAL WOOD-FRAME CONSTRUCTION IN CANADA – ID 463

*T. White, University of British Columbia, Canada*
*C. Ventura, University of British Columbia, Canada*
*G. Taylor, TBG Seismic Consultants Ltd., Canada*

Over 95% of all residential buildings in Canada are of wood-frame construction. The design and construction of wood-frame buildings is governed by the 2005 National Building Code of Canada. However, most residential wood-frame construction does not have to be specifically designed to resist earthquakes. While much of Canada has little to no seismicity, parts of the West Coast of Canada and the St. Lawrence Valley have a moderate to high seismic hazard. The 1994 Northridge earthquake in California demonstrated that both existing and new wood-frame buildings do have a significant seismic risk and when not addressed can lead to the loss of property and life. In 1999 the University of British Columbia (UBC) and its industry partners undertook an extensive experimental program focusing on local wood-frame construction practices. The tests included static and dynamic testing of stucco, plywood, gypsum and horizontal board panels, as well as shake table testing of a series of full scale two-storey wood-frame houses. This paper describes the modeling and validation of a set of two-storey wood-frame houses. Models were built for SAWS, a non-linear dynamic analysis program developed as part of the CUREE Wood-frame project, and FEMA-440's Displacement Coefficient Method. The models were calibrated against the static tests from UBC, and validated with the results from the shake table testing. The outcome was a set of performance curves and minimum strength requirement tables for residential wood-frame construction with four different types of exterior sheathing commonly found on the West Coast of Canada. The minimum strength tables were based on seismic provisions of the 2005 National Building Code of Canada.

## SEISMIC PERFORMANCE OF MASONRY WALLS USING INTERLOCKING UNITS – ID 508

*Y. Sanada, University of Tokyo, Japan*
*Y. Nakamura, Niigata University, Japan*
*N. Yamauchi, University of Tokyo, Japan*
*Y. Nakano, University of Tokyo, Japan*

This paper presents a method to improve seismic performance of unreinforced masonry (URM) walls by using interlocking masonry units. Two new URM wall specimens, consisting of brittle and ductile interlocking units (Wall-BI and Wall-DI, respectively), were designed and tested. Although brittle units were made of brick, ductile units were made of fiber reinforced cement composite, specially produced for Wall-DI. The seismic performances of Wall-BI and Wall-DI were compared with another typical masonry wall specimen (Wall-C), using conventional bricks. Although Wall-C failed in shear at a small drift level, flexural behaviors were observed in Wall-BI and Wall-DI. As a result, the lateral strengths of Wall-BI and Wall-DI were much higher than that of Wall-C. In Wall-BI, however, the strength degradation was observed at a larger deformation. This was caused by lateral force resisting characteristics of URM walls, using brittle interlocking units. On the contrary, no degradation was observed up to 1/50 drift level in Wall-DI. Therefore, it was experimentally verified that URM walls could be effectively strengthened using interlocking masonry units. Moreover, ductile interlocking units could improve the ductility as well as the strength of URM walls.

## SEISMIC STRENGTHENING AND REPAIR OF THE SS. PETER AND PAUL CHURCH IN OHRID - CASE STUDY – ID 527

*V. Sendova, IZIIS-Skopje, Macedonia*
*B. Stojanoski, IZIIS-Skopje, Macedonia*
*R. Salic, IZIIS-Skopje, Macedonia*
*M. Garevski, IZIIS-Skopje, Macedonia*

The town of Ohrid with its surrounding represents a mosaic of Orthodox religious structures which, according to their function represent not only spiritual but also cultural and social medium of modern living. It is therefore that further existence and protection of these structures has been and is of particular interest for society and science. One of these structures is the Orthodox church of Ss. Peter and Paul in the village of Mesheista, Ohrid dating back to the end of the 19th century. During its serviceability period, this church has suffered visible damage concentrated in the domes and the vaults as well as in the upper middle part of the northern facade due to uneven soil settlement which imposes the need for consolidation, repair and strengthening of the existing structure. The selected concept of structural strengthening and repair aimed at reaching the necessary level of stability under gravity and seismic loads has been selected based on: (i) Previous investigations (architectural survey, geomechanical investigations, definition of the main dynamic characteristics as well as definition of the physical mechanical characteristics of the built-in materials); (ii) Seismic safety design criteria according to the existing valid regulations; (iii) IZIIS' recent knowledge and developed methodology for seismic protection of cultural-historic structures. Structural strengthening has been done by incorporation of vertical reinforced-concrete jackets on the external side of the bearing walls and horizontal reinforced-concrete belt courses at the level of the domes as well as by insertion of steel ties beside the existing timber beams anchored into the vertical reinforced-concrete jackets. The selected concept of structural strengthening and repair enables complete protection of the lavish fresco paintings inside the structure. The results from the detailed analysis have shown that the repaired and strengthened structure completely satisfies the prescribed safety requirements and criteria for such historic structures.

## SEISMIC RESISTANCE OF DIFFERENT TYPES OF VERTICALLY PERFORATED BRICKS – ID 534

*E. Fehling, Institute of Structural Engineering, Germany*
*J. Stürz, Institute of Structural Engineering, Germany*

The state-of-the-art in design of masonry walls subjected to lateral loads together with the increased loads by wind and earthquake according to the new generation of European Design Codes (Eurocodes) in many cases does not allow to prove sufficient bearing capacity for load bearing masonry structures as they are built until now. To get a better understanding of the load bearing mechanisms, tests on masonry walls with realistic dimensions have been carried out. A main difficulty of such tests is to reproduce all boundary conditions for a representative part of masonry walls. So the existing lateral resistance test methods are going to be

evaluated and a suitable test setup for a harmonised European standardisation is going to be developed within the frame of the ESECMASE, a research programme funded by the EU and the masonry industry. By the use of this new test setup several tests on masonry walls of different kinds of vertically perforated bricks are going to be carried out under static-cyclic loading. At this, the effect of the perforation of the bricks on the load bearing capacity of the wall will be shown. The test results on walls with different wall lengths and different vertical loading will be used to assess the current design model and to identify possible improvements.

### SEISMIC REHABILITATION OF MASONRY SCHOOL BUILDINGS USING A SINGLE LAYER OF REINFORCED SHOTCRETE – ID 535

*T. Honarbakhsh, Sarzamin Cosultant Engineers, Iran (Islamic Republic Of)*
*A. Rahnavard, Sarzamin Cosultant Engineers, Iran (Islamic Republic Of)*
*M. Kazemi, Sharif University of Technology, Iran (Islamic Republic Of)*

Masonry buildings represent the largest portion of the school buildings in Iran. Some of these buildings consist of plain brick masonry walls confined with concrete tie columns and bound beams, but with a poor design and with very poor and unreliable construction. In depth seismic evaluation of some of the masonry schools in Tehran revealed their need for an extensive rehabilitation program. Most of the tie columns and bound beams lack reliable connections and the integrity of entire structures does not exist. Based on vast study of various rehabilitation techniques, application of reinforced shotcrete on the only one of two faces of brick masonry bearing walls, found as an effective solution for the masonry school buildings. The interior faces of exterior bearing walls were used for jacketing. Simple calculations, as well as finite element non linear analysis, showed that one-sided jacketing of masonry walls, with proper bonding of masonry to the new reinforced mortar jacket, might provide adequate strengthening for the structure. Also, the analysis has demonstrated the large strength capacity of wall panels subjected to loads in the both outward and inward out-of-plane directions. Three masonry school buildings were rehabilitated, during summer holydays of 2005, using single sided mortar jacket, reinforced with welded wire fabric. Jacketing was implemented from the foundation to the roof. The strengthening cost about 25 per cent of the value of the similar new school buildings. The brick masonry facade and the architecture of schools left, almost, unchanged.

### AN OVERVIEW ON THE MATERIAL PROPERTIES OF HISTORICAL STRUCTURES IN SEISMIC REGIONS OF ANATOLIA – ID 553

*C. Demir, Istanbul Technical University, Turkey*
*M. Ispir, Istanbul Technical University, Turkey*
*A. Ilki, Istanbul Technical University, Turkey*
*N. Kumbasar, Istanbul Technical University, Turkey*
*S. Akman, Istanbul Technical University, Turkey*

Historical structures should be preserved due to their cultural and historical value. An extensive multidisciplinary study is necessary to take appropriate measures for the seismic protection of these structures. Since historical structures exhibit various characteristics depending on their construction period and location, it is a challenging work for the structural engineer to asses the seismic safety and take necessary measures in order to prolong the life-span of these structures against seismic events. During the structural analysis of historical structures, determination of material properties is one of the most important steps, which will affect the results of the study.

Anatolia, which has been effected by catastrophic earthquakes throughout the history, has been inhabited by various civilizations such as Hittites, Greeks, Romans, Byzantines, Seljuks and Ottomans. Each civilization had developed or adopted a diversity of masonry construction techniques and masonry components. Depending on the techniques and materials, masonry structures can roughly be classified as adobe masonry, stone masonry, dry-stone masonry, sack masonry, brick masonry, and mixed masonry. Consequently, the form of masonry and material characteristics play an important role in the seismic performance of these structures. In this study, a compilation of the research on the material properties of ancient masonry structures built in Anatolia has been done. Although it is difficult to form a general judgment on the mechanical, chemical and physical characteristics of masonry components such as bricks, stones and mortars, it may be possible to make an attempt to have an overview. During the compilation of the available data, case-studies and historical documents were utilized as well as the data obtained from scientific researches. As the great proportion of adobe masonry structures have vanished through the history, this paper does not include adobe masonry structures.

### DAMAGE EVALUATION AND REHABILITATION OF THE MONTORIO MEDIEVAL TOWER – ID 677

*M. Indirli, ENEA, Italy*
*B. Carpani, ENEA, Italy*
*B. Spadoni, ENEA, Italy*

On 14th September, 2003, a moderate earthquake (local time 23:43; Magnitude Ml 5.0; MCS Intensity VII, focal depth about 20 km) struck the Bolognese Apennines, with the epicenter near Monghidoro (30 km far from Bologna, Italy). The seismic event, felt in a sufficiently large area, showed an inhomogeneous damage distribution, due both to site effects and building different vulnerability. In particular, several historic constructions were subjected to relevant damage, mainly churches and ancient monuments, including the Tower matter of this paper, which is located at Montorio, not far from the earthquake epicenter. The authors, involved in the on-site Civil Defense investigations, carried out a detailed geometric, structural, and damage survey on the above mentioned medieval monument. The ancient five-floor Tower (10 x 10 m large), together with its subsequent additions in historic times, is a still lived-in complex, principally constructed with sandstone and river pebbles masonry. The wall tissue (about 1 m width) is generally enough accurate, showing regular horizontal courses and bigger squared quoins at the corners; unfortunately, local defects, failures and settlements are somewhere evident; in addition, the mortar joints are often degraded and lacking of maintenance. The wooden roof doesn't show string-courses, but the presence of wooden trusses along the top of the external walls. The building (declared unsafe) showed heavy and spread damage to many structural elements, including vertical walls and wooden floors, with one level of intensity more than the pattern suggested by macroseismic data. The paper carries out a discussion regarding the seismic input and its consequences on the historic monument, together with a detailed analysis of the structural characteristics. Finally, the paper also speaks about the post-seismic rehabilitation intervention, which has to be foreseen compatible with the "regola dell'arte", avoiding a possible conflict between specific conservation criteria and antiseismic requirements.

### CYCLIC BEHAVIOR OF TENON-MORTISE CONNECTIONS OF TRADITIONAL TIMBER FRAMES OF KOREA – ID 715

*S. G. Hong, Seoul National Univ., Korea, Republic Of*
*Y. W. Lee, Kunsan National Univ., Korea, Republic Of*
*J. K. Hwang, Korean National University of Cultural Heritage, Korea, Republic Of*
*N. Kim, Seoul National Univ., Korea, Republic Of*
*S. J. Jung, Hannam, Korea, Republic Of*

This paper presents experimental results of typical tenon-mortise connections which integrates architraves and columns in traditional timber frames of Korea. A series of quasi static cyclic test programs were performed to investigate initial stiffness strength, and hysteretic behaviors of such connections of a timber frame in the long direction. In order to investigate the rotational behavior of tenon-mortise connections under consideration with interaction of

flat beams on the top of architraves, different dimensions of mortises and bearing stress magnitudes from roof gravity loads on capitals were selected as main variables influencing connection behaviors in the experimental program. Such variables represent friction devices of joints dissipating energy. The experimental results of a frame are explained by the supposition of individual connection behaviors. Typical bilinear behaviors with the high damping of connections are supposed to contribute the ductile behavior of traditional timber frames of Korea.

Keywords: Traditional Timber Frames, Tenon and Mortise Connections, Quasi Static Cyclic Load, Friction Devices, Damping

### FULL SCALE SHAKING TABLE TESTS FOR POST AND BEAM STRUCTURE OF WOODEN HOUSES BY E-DEFENSE – ID 733

*I. Sakamoto, University of Tokyo, Japan*
*S. Yoshiyuki, Kyoto University, Japan*
*M. Chikahiro, NIED, Japan*
*N. Izumi, NIED, Japan*
*S. Hidemaru, NIED, Japan*

The construction of a three-dimensional full-scale earthquake testing facility named E-Defense was completed in March 2005, and the shaking table tests for wooden house models were conducted using the facility. The purpose of the test was to investigate the seismic performance of the wooden houses, and to clarify the effects of the seismic resisting method. Three types of models used in the test: The conventional Japanese post-and-beam type wooden houses, the traditional wooden houses, and the wooden house with base isolation system. In the test using conventional Japanese post-and-beam type wooden houses, two wooden houses built before 1981 Japanese Building Standard Law were dismantled and reconstructed on E-Defense. One of the houses was reinforced, and the other was changed nothing. These two models were set on E-Defense and tested simultaneously. As a result, the model without reinforcement collapsed by the input motion recorded at JR Takatori station in 1995 Hyogo-ken Nambu Earthquake, but the model with reinforcement withstood the motion. The test results clearly showed the adequacy of the current seismic diagnosis and the reinforcement method. The test for the traditional wooden houses also used two types of models. One of the models was actually built in Kyoto-city and reconstructed on E-Defense for this experiment. The other model was a newly built wooden house, which has almost same plan with moved one but newly designed wooden frames. Through the test, the seismic performance of the traditional wooden houses was clarified. The effect of seismic resistance method suitable for the traditional wooden houses was also investigated. In the test for the wooden house with base-isolation system, the performance of base isolation system for houses under destructive earthquakes was investigated. The effect and the limit of the base isolation system were shown through the test.

### BEHAVIOUR OF MASONRY STRUCTURES SUBJECTED TO EARTHQUAKE GROUND MOTIONS – ID 740

*K. S. Jagadish, Indian Institute of Science, India*
*S. Raghunath, B.M.S.College of Engineering, India*
*K. S. R. Nanjunda Rao, Indian Institute of Science, India*

It is well known that unreinforced masonry structures are highly vulnerable to earthquake ground motions. The masonry structures in developing countries are even more vulnerable as they utilize rather weak mortars. Several codes of practice have emerged to improve the seismic resistance of such structures. However, the practices suggested by the present codes often do not address the issues arising out of the failure pattern of masonry. In this paper, an attempt is made to understand modes of failure of masonry buildings, when subjected to strong ground motions, based on reports of damage during past earthquakes. Some of the traditional techniques used to improve seismic resistance of buildings are discussed with reference to modes of failure. The typical frequency and mode shape characteristics of masonry buildings and typical strength of masonry elements in developing countries are discussed. The currently recommended codes of practice are examined in the light of observed failure modes and the importance of out-of-plane failure of masonry walls is emphasized. The inadequacy of the present codes of practice to meet the out-of-plane flexural strength requirements is brought out. Alternative method like use of "containment reinforcement" for better earthquake resistance is discussed.

### APPLICATION OF SEISMIC ISOLATION AND DEVICES FOR DISSIPATION OF SEISMIC ENERGY TO MASONRY STRUCTURES – ID 924

*B. Bulajic, The Highway Institute, Yugoslavia*
*M. Manic, IZIIS, Macedonia*
*S. Djurdjevic, The Higway Institute, Yugoslavia*

Purpose of this paper is to discuss the capabilities of application of some new seismic protection technologies to masonry structures. Application of seismic isolation is, mainly due to its cost (but also due to the restrictions of the most seismic codes), still limited exclusively to buildings of outstanding national significance (e.g., old churches, historical monuments, etc.). As far as devices for dissipation of seismic energy are concerned, conceivable engineering and economical justification of their application can be proved only after detailed experimental and analytical investigations, since only in this manner it is possible to ascertain the extent to which the particular device is capable of helping structure to resist earthquakes.

### SEISMIC BEHAVIOR OF TRADITIONAL HERITAGE WOOD STRUCTURES IN KOREA – ID 930

*N. Kim, Seoul National University, Korea, Republic Of*
*S. G. Hong, Seoul National University, Korea, Republic Of*
*J. K. Hwang, Korean National University of Cultural Heritage, Korea, Republic Of*
*Y. W. Lee, Kunsan National University, Korea, Republic Of*
*S. J. Jung, Hannam University, Korea, Republic Of*

Many Korea traditional heritage wood structures have shown their excellent structural performance over more than 400 years. Recent research on the old heritage wood structures has focused on the structural behavior of traditional wood structures of national heritage under earthquake loadings in Korea. A series of experimental tests were performed on a frame with a lintel by tenon-mortise joint and brackets to investigate seismic performance including the characteristics of initial stiffness, behavior after ultimate loads, and hysteretic behavior. This paper first describes dominant structural features of Korean traditional heritage wood structure from the point of earthquake-resisting view: structural components, plan and configuration, tiers and structural tenon-mortise joints and brackets. Along with these features, some experimental test results are then discussed in terms of force-displacement relationships to provide a global overview of the seismic behavior. This study is expected to address some problems due to lack of knowledge about the seismic capacity of existing old heritage structure in its structural assessment.

### SEISMIC BEHAVIOR OF MASONRY HOUSES RETROFITTED WITH PP-BAND MESHES EVALUATED WITH SHAKING TABLE TEST – ID 962

*J. P. Mayorca Arellano, University of Tokyo, Japan*
*K. Meguro, University of Tokyo, Japan*
*N. Sathiparan, University of Tokyo, Japan*
*R. Guragain, University of Tokyo, Japan*
*N. Nesheli, University of Tokyo, Japan*

Human casualties due to earthquakes are mostly due to structural collapse mainly that of unreinforced masonry buildings. The existing world housing stock is mostly composed of this type of seismically vulnerable dwellings. Retrofitting of low earthquake-resistant masonry structures is the key issue to significantly reduce casualties in future events. In addition, it decreases the costs of

rescue and first aid activities, rubble removal, temporary residence building, and permanent residence reconstruction to re-establish normal daily life, contributing to the sustainability of the affected countries' development. In order to effectively promote seismic retrofitting, it is essential to develop inexpensive technical solutions which can be executed without highly skilled labor. In this context, the use of polypropylene band (PP-band) meshes has been proposed as a feasible option. These bands, commonly used for packing, are resistant, inexpensive, durable and worldwide available. The applicability of PP-band meshes to retrofit unreinforced masonry structures has been previously tested under static loads. In this presentation, the results of 1/4 scale shaking table tests of unreinforced masonry models without and with PP-band mesh retrofitting are reported. Under dynamic loading conditions, the retrofitted models exhibited excellent performance, showing increased ductility and maintaining a life safety performance level for shakings of intensity JMA 6-. As observed in former static tests, the models with and without meshes behaved similarly before the initial cracking. However, the unreinforced specimens collapsed abruptly after few cracks developed. The retrofitted models, on the other hand, exhibited extensive cracking, which allowed them to dissipate energy through sliding along the cracked mortar joints. The reported shaking table tests corroborated that PP-band mesh retrofitting can effectively improve the seismic performance of unreinforced masonry structures at a very affordable cost. Furthermore, the intervention hardly alters the living environment and therefore is highly acceptable by the public.

### THE INFLUENCE OF GEOMETRY ASPECT RATIO AND MASONRY BOND ON THE SEISMIC BEHAVIOUR OF MASONRY WALLS – ID 974

*M. Tomazevic, Slovenian Nat. Bldg. and Civ. Engrg. Institute, Slovenia*
*V. Bosiljkov, Slovenian Nat. Bldg. and Civ. Engrg. Institute, Slovenia*

The results of experimental research in seismic behaviour of clay hollow unit plain masonry walls are discussed. The influence of geometry aspect ratio (height to length ratio) of the walls as well as the type of masonry bond (filling of vertical joints) on the mechanism of seismic behaviour has been studied. A series of 14 walls has been built in the laboratory by using hollow clay units and general purpose mortar. In the first case, the walls have been 250 cm long, 175 cm high and 30 cm thick (aspect ratio 0.7), whereas in the second case, the walls have been 100 cm long, 150 cm high and 30 cm thick (aspect ratio 1.5). Each type of the walls has been constructed by either fully filled (BN) or not filled vertical mortar joints (BZ). The walls have been constructed on r.c. foundation blocks and tested as vertical cantilevers by subjecting them to cyclically imposed horizontal displacements at two different levels of constant vertical precompression. Shear mode of failure has been observed in all cases, with rocking observed previously in the case of the slender walls at low level of precompression. It has been found that in the case of both geometry aspect ratios of the walls the tensile strength theory proposed by Turnšek and Čačovič (1970) provides more consistent results than the equations proposed in Eurocode 6. It has been also found that in the specific case of the masonry walls tested, the behaviour of the walls has been governed by relatively brittle local failure of units. Consequently, no difference in the behaviour of the walls with filled and not filled vertical joints could be observed. Additional experimental research is needed to provide information regarding the use of ungrouted vertical joints in seismic zones.

### EXPERIMENTAL RESPONSE OF REINFORCED MASONRY WALLS RETROFITTED WITH CARBON FIBER FABRICS – ID 975

*H. Santa Maria, Universidad Catolica de Chile, Chile*
*P. Alcaino, Universidad Catolica de Chile, Chile*

The extensive damage that masonry wall buildings have suffered during recent earthquakes has shown the need of new reinforcing techniques for the structural retrofit of those buildings. A new reinforcing technique consists of fiber reinforced polymers externally bonded to the sides of the walls. As part of an on going investigation the shear behavior of brick masonry walls with steel wire as shear reinforcement were retrofitted with Carbon Fiber fabric externally bonded to the surface of the walls. A total of 4 - 197 by 200 cm masonry walls were subjected to cyclic, in plane shear loads. Three walls were externally reinforced in both sides with carbon fabric with two different configurations to improve their shear response: horizontal reinforcement and diagonal reinforcement (in the shape of an X). The experimental results showed that Carbon Fiber fabric applied to the walls provide a less destructive failure mode and an increase of the maximum strength. The response of the shear walls with different reinforcement configurations was compared in terms of strength, failure mechanism, energy dissipation capacity, and deformation capacity. Also an analytical model was compared to the experimental results. As future work 10 - 197 by 200 cm masonry walls, with various configurations of exterior fabric reinforcement (including single side reinforcement), will be tested, and a design methodology will be proposed.

### SEISMIC BEHAVIOUR OF VIMIOSO CHURCH. NUMERICAL VERSUS IN SITU STUDY – ID 1014

*B. Silva, FEUP, Portugal*
*A. Costa, UA, Portugal*
*J. Guedes, FEUP, Portugal*

The increasing importance given to the conservation and rehabilitation of monuments supports the significant number of numerical studies that have been performed on stone masonry structures; in particular, their behaviour under seismic loading is an issue that should not be neglected. Understanding how stone masonry structures behave under dynamic horizontal loads yields important information on possible collapse mechanisms and damage progression along the structure. In this paper, an old masonry structure, the Vimioso Church, is analysed using a numerical model. This church sustained important damage, still visible nowadays, due to previous earthquakes, namely the 1755 Lisbon earthquake. Other effects, such as foundation settlements, also contributed to the actual state of the church. The structure was numerically simulated with the Cast3M software environment, using 3D finite elements and a linear elastic behaviour model. Natural frequencies were computed and compared to the frequencies determined in situ using seismographs placed on the upper surface of the ceiling vaults and on the top of the walls. This comparison allowed to fit the mechanical properties of the church structural elements. The calibrated numerical model of the church was then submitted to an artificially generated accelerogram matching the church site conditions and the probable intensity of the 1755 Lisbon earthquake. Results of the dynamic analysis are presented and discussed, and structural damage is compared to the observed damage in the real structure, namely in terms of maximum deformations and damage patterns. Such studies allow not only for a better knowledge on the structural behaviour of stone masonry constructions, but they will also permit the definition of more effective retrofitting and/or strengthening solutions.

### ASSESSMENT OF THE STRUCTURAL BEHAVIOR OF A MASONRY WALL UNDER HORIZONTAL CYCLIC LOADS – ID 1020

*A. Costa, FEUP, Portugal*
*B. Silva, FEUP, Portugal*
*A. Costa, UA, Portugal*
*J. Guedes, FEUP, Portugal*
*A. Arêde, FEUP, Portugal*

This paper presents a numerical and experimental study on the cyclic behaviour of a wall from a two floors house located at the parish of Pedro Miguel, Horta council, Faial Island of the Archipelago of Azores. The wall was located on the first floor between two main doors of the house façade. It is a traditional two-sleeve masonry wall filled with a with low cohesion poor material, typical of the constructions of this Archipelago. On

the outside, the wall was covered with mortar. The wall was transported by sea from its original site to the Laboratory for Seismic and Structural Engineering of the Faculty of Engineering of Porto University (LESE - Laboratório de Engenharia Sísmica e Estrutural da FEUP). It was set on a reinforced concrete block and a highly rigid mixed structure of concrete and steel was placed at the top of the wall to allow a uniform distribution of the horizontal and vertical loads applied during the cyclic test. After the first experiment, the wall was reinforced using the same technique used in Azores during the reconstruction programme. At the same time, the wall was simulated numerically with finite elements and different behaviour models for the stones, the infill and the joints. The paper describes the experimental setup and presents the analysis and interpretation of the outcome of the laboratory tests. It also describes the numerical model and compares the numerical to the experimental results in order to check the efficiency of the model to simulate the behaviour of such a heterogeneous structure.

## SEISMIC ASSESSMENT OF EXISTING MASONRY BUILDINGS – ID 1067

*G. Magenes, Dept. Structural Mechanics - University of Pavia, Italy*
*A. Penna, EUCENTRE, Italy*

The new Italian Code for seismic design and assessment (OPCM 3274/2003) provides innovative criteria for the evaluation of existing masonry buildings distinguishing global response and local damage mechanisms. Local mechanisms are related to the specific vulnerability of single structural elements: mechanisms involving the out-of-plane behaviour of masonry walls, overturning of slender elements such as chimneys or parapets, damage mechanisms in masonry arches and vaults and other kind of interaction effects in buildings aggregates, like pounding in the case of unilateral joints. Procedures based on limit analysis approaches can be used in order to assess the lateral capacity and the seismic vulnerability of these elements to the potential local mechanisms. Effective connections between the different parts of the structure (connection between orthogonal walls and between walls and floors) can prevent the activation of early local mechanisms and allow the masonry building to express a dynamic global behaviour governed by the in-plane strength and stiffness of walls and floors. As suggested in the code, the non-linear in-plane response of walls can be modelled by means of macro-element structures (e.g. frame-type) made of deformable elements, masonry piers and spandrel beams, tie-rods and r.c. ring beams, which have to comply with the code prescriptions in terms of failure modes and displacement limit states. Starting from the seismic evaluation of a case study building, the whole assessment procedure is shown and several key points are focused on the single steps, both regarding local damage mechanisms, evaluated by means of linear and non-linear kinematical approaches, and global response, calculated by non-linear pushover analysis.

## THE VULNERABILITY STUDY OF MASONRY STRUCTURES IN HUNGARY – ID 1116

*O. Kegyes-Brassai, Budapest University of Technology and Economics, Hungary*

Determining the earthquake risk of building stocks or settlements has lately become a prominent issue. Recently the new structures should also be designed according to EC8 in Hungary. Hungary counts to the medium hazardous countries however it was not a practice dimensioning against earthquakes. Moreover the wind loads were bigger than those gained from earthquake loads. The earthquake loads were underestimated, so with the new standard there is a large building stock that needs reinforcement. This emphasises the importance of assessment of building vulnerability. The paper presents a comparison between the shear capacities of masonry buildings and the calculated shear forces obtained from loads offered by EC8 based on the national earthquake hazard map. (The peak ground acceleration is 1,14 m/s2 in Győr.) This is presented through two examples. Stress should be laid on prevention. By assessing the buildings it can be determined which are the constructions that need to be reinforced against earthquakes and a priority list of interventions can be established. This can decrease the expected damage during an earthquake. The main conclusion of the paper consists of the necessity of supervision and reinforcement of several buildings in Hungary.

## REHABILITATION AND STRENGTHENING OF ST. EUSTAHIUS CHURCH MASONRY STEEPLE – ID 1119

*M. Ulicevic, University of Montenegro, Yugoslavia*

This paper deals with the rehabilitation and strengthening of 39 m high St. Eustahius church masonry steeple in Boka Kotorska bay that belongs to Montenegrin cultural heritage built in 18th century. The pyramidal bells lodge and three tons weight St. Eustahius statue on the top of the steeple have been damaged seriously in year 2000 by the action of lightning. However, it was diagnosed by refined inspection that initial damages occurred previously as the consequences of lower and medium intensities earthquakes action over past two centuries.

The steeple masonry structure has modelled by solid finite elements and soil-structure interaction has also included. The dynamic response of structure has analysed for both design seismic action (revert period of 475 years) and for the damage limitation requirement (revert period of 95 years), according to EC 8 (ground type C). In addition, time-history FEM analyses carried out for five different inputs - recorded and scaled accelerograms, in order to define the measure of structure vulnerability. Non-linear analysis i.e. changing in masonry stiffness and P-Delta effects have also considered.

It is found that the influence of higher modes of oscillations is evident in upper part of steeple. This confirms that initial damages could occur even under lower seismic action. Also, it is emphasized that the composite of input earthquake data strongly affects on dynamic behavior of this type of structure. Therefore, sufficient number of different input data sets should be applied in analysis.

In order to satisfy both specific conservation and restoration requirement and durability in aggressive maritime climate conditions, the rehabilitation and strengthening solution is based on stainless steel tendons built-in through rock bells lodge elements.

## MECHANICAL PROPERTIES OF MASONRY MATERIALS IN PAKISTAN – ID 1237

*A. Qaisar, NWFP UET, Pakistan*
*N. Akhtar, NWFP UET, Pakistan*
*A. Mazhar, NWFP UET, Pakistan*

A huge proportion, approximately 60%, of the building stock in Pakistan comprises Unreinforced Brick Masonry (URM) buildings. Of these 90% are concentrated in cities whereas 10% lie in villages. In the October 08 earthquake of Pakistan, it was observed that these buildings performed excellently well as compared to stone and block masonry buildings. As part of this study, a comprehensive testing program was launched in the Earthquake Engineering Center of the University of Engineering and Technology Peshawar to determine the mechanical properties of materials used in such buildings for onward evaluation of their seismic capacity. This paper presents results from around 1000 various tests conducted on masonry materials covering almost all types of Unreinforced Masonry practiced in Pakistan.

## BEHAVIOUR OF MASONRY BUILDINGS STRENGTHENED WITH GFRP GRID BONDED WITH CEMENTITIOUS MATRIX – ID 1280

*F. Venuti, CESI S.p.A., Italy*
*G. Bergamo, CESI S.p.A., Italy*
*I. Langone, CESI S.p.A., Italy*
*M. Eusebio, CESI S.p.A., Italy*
*G. Manfredi, University of Naples Federico II, Italy*

Within the framework of project TE.M.P.E.S., focused on the development of innovative techniques for seismic upgrade of historical masonry structures, tests on two tuff masonry model structures have been conducted to evaluate the effects of

different criteria and tools for seismic retrofit. Shaking table tests were performed on representative model structures with the 3D MASTER shaking table operating at the structural laboratory of CESI, Seriate, Italy. The two stories tuff masonry tested building was a 1:2 prototype characterized by in-plane dimensions of 2.60m x 2.85m and a total height of 3.20 m. The three-leaf type of masonry is typical of many structures in Europe and in the Mediterranean area. The prototype has been tested at increasing seismic intensity levels [Calitri, 1980] until a significant level of damage was observed. Then the damaged prototype has been strengthened and retested using the same earthquake to validate an innovative technique based on a GFRP matrix bonded using a cementitious mortar. This solution is based on the concept of the traditional reinforced plaster realized using a steel grid placed into a concrete layer. However, it could be several advantages related to the following: almost no influence on elastic stiffness due to the small thickness (i.e., about 10 mm), ease of installation, durability, compatibility with the masonry substrate, reversibility. On the base of the obtained experimental results, the GFRP grid were installed on the weak walls only. The accelerometer and displacement signals recorded at the monitored points of the as-built and repaired prototype have been analyzed. Numerical analyses using a different numerical approaches (FEM/DEM) have been performed to simulate the dynamic behavior of the prototype. The obtained numerical and experimental results have been related to the specific rules suggested by the Italian and European Masonry Building and Seismic Codes [DM 1987/96, EC6, OPCM 3274, EC8].

### 3D DYNAMIC TESTS ON 2/3 SCALE MASONRY BUILDINGS RETROFITTED WITH DIFFERENT SYSTEMS – ID 1378

*M. Dolce, DiSGG, Italy*
*G. De Canio, ENEA, Italy*
*A. Goretti, SSN-DPC, Italy*
*R. Marnetto, TIS SpA, Italy*

Traditional masonry buildings are very common in all the old Italian historical centres. According to the actual detailing, their vulnerability can be very high, as proven by all recent Italian earthquakes, even of moderate magnitude. The TREMA project (Technologies for the Reduction of seismic Effects on Architectural Manufacts) provided the chance to evaluate the dynamic performance of 3D masonry buildings, seismically retrofitted with different systems. Two identical 3D models, 2:3 scale, were constructed. The model dimension were selected according to the traditional practice of construction, also considering that the total weight of the building was limited by the crane capacity to 200KN. The model has two stories, external plan dimension 300x350 cm, total height 420 cm, thickness of walls 25 cm. Tufa stone masonry wall were constructed with low quality mortar. Floor and roof were made of wooden boards 2 cm thick on rafters 10x18 cm. Door and window openings have wooden lintels. Additional masses were placed on floor and roof in order to respect the scaling laws. Both models were placed on the shaking table and subjected to a increasing intensity suitably scaled input motion, to simulate the simultaneous three components of Colfiorito, 1997 Umbria-Marche earthquake. One of them was initially tested in a base isolated configuration up to slight damage. Then it was strengthened with the CAM system, consisting of stainless steel tightening horizontal and vertical ribbon. The other model was fixed at the base and tested up to near-failure conditions. Besides accelerometric and displacement data, macroscopic observation of the response was systematically recorded by digital cameras. In the paper the main results of the experimental tests are described and the behaviour of the model under the seismic excitation is discussed. Considerations on the model failure are also made.

### DESIGN METHODOLOGIES FOR THE ASSESSMENT OF THE SEISMIC PERFORMANCE OF MASONRY WALLS – ID 1380

*R. Popescu, IPCT Structuri, Romania*
*G. Popescu, IPCT Structuri, Romania*

The methodologies was elaborated for unreinforced masonry walls, subjected to lateral in-plane forces. The method is suitable for both new and existing buildings and for the retrofiting of the existing masonry buildings in seismic areas. Three deformation stages considered are: cracking, yielding in compression , ultimate. The shear strength is determined at the intersection of the limit curves: the curve corresponding to shear failure and the curve corresponding to failure in bending and compression stress. For the basic shapes of sections (rectangular, T- or I-shaped) a simplified method, adequate to manual calculations, was derived. For complex shapes of sections, the basic method is applied, which requires the use of a computer program. The method was applied in a numerical study, presented in the paper. For three shapes of wall, the relation between axial stress and shear stress was plotted for three different distributions of shear stresses across the flange in compression.

### REPAIR AND STRENGTHENING OF ANCIENT STRUCTURES – ID 1387

*H. Sesigür, Istanbul Technical University, Turkey*
*O. C. Celik, Istanbul Technical University, Turkey*
*F. Cili, Istanbul Technical University, Turkey*

In recent years, significant developments were recorded in the field of repair and strengthening techniques of ancient cultural heritage structures. However, traditional retrofitting techniques are rather preferred to improve the seismic behaviour of those structures. This study mainly aims to evaluate the effectiveness of seismic retrofitting of historic masonry domes by a steel ring placed at their support level. In the present article, the problem is considered through examples of real conservation cases involving an ancient mosque's dome, The Ahi Celebi Mosque, 529 year old, a bath's dome, The Süleymaniye Bath, 449 years old and an Ottoman Archieve Building's roof, 449 year old, in Istanbul. These structures are subjected to gravity and seismically originated forces and analyzed with structural analysis program (SAP2000) using FEM. The behaviour of the selected masonry dome systems before and after the retrofitting is analyzed and compared. Also, the site observations are explained in detail.

### PERFORMANCE OF MASONRY STRUCTURES – ID 1392

*Ö. Isler, Istanbul Technical University, Turkey*

In this paper, the performance of masonry buildings during 1998 Adana and 2003 Bingol (in Turkey) Earthquakes are presented. The moment magnitudes of these earhhquakes are occurred as, 5.9 and 6.4, respectively. In these earthquakes, many buildings were heavily damaged and some have totally collapsed. The characteristical damages are observed and their damage reasons are investigated. Because of the damage reasons are; i) Separations in upper tips of corner joints of flat roof, ii)Deterioration in the stone walls as a result of the clay mortar's loosing its binding properties through the seasonal effects, iii) There are not enough spaces between the corners and the windows/doors, in this case, the cracks resulting in moderate damage and/or collapse in the wall. iv) The log beams which bearings the landfill flat roof break loose and the roof collapses. v) The damages are greater in buildings constructed with only lime mortar instead of lime and cement mortar. It has been noted that natural stone has been used for wall material and mud mortar has been used as binding material and that landfill flat roof are supported by these stonework walls in these two storey local buildings with their lower story being barns. and important damages emerge as a result of this depending on the thickness of the wall. 1998 Adana and 2003 Bingol Earthquakes have shown us once again, that the inadequacy of seismic design project and application along with poor material and workmanship, are the main reasons for the damages in the masonry buildings.

### CONSOLIDATION OF THE ARCHEOLOGICAL SITE OF KHOR RORI (OMAN) – ID 1394

*M. Sassu, University of Pisa, Italy*
*M. Andreini, University of Pisa, Italy*
*C. Cei, University of Pisa, Italy*
*G. Mariani, University of Pisa, Italy*

The ruins of the ancient city of Khor Rori (4th century A.D.) in Oman are bounded by walls of considerable thickness (up to 4 m.). The walls' masonry and their infrastructures are made up of two poorly worked limestone or sandstone external layers. In their centres is a disorganized mixture of unselected ground materials, mostly sand and clay. There are now large sections of the walls that show marked signs of subsidence attributable to the poor quality of the inner plaster mixture, exposing them to transverse earthquake collapses and the effect of the monsoon seasons due to the lack of topside protection from the rain. Essentially two types of collapse have been encountered:

a) expulsion of the outer facings caused by the transverse pressure exerted by the random inner clay-sand mixture, due to loss of cohesion and meteoric washout. b) expulsion of the outer brick layers and the internal mixture of the thicker walls.

In order that the structurally damaged walls be rebuilt in accordance with UNESCO guidelines, intervention should proceed as follows:

1- Reducing the internal transverse loads, by way of partial calcification of the inner random mixture in order to afford it permanent cohesion. 2- Preventing rain seepage from the top by protecting the upper part of the walls through addition of a layer of "poor lime mortar" to form a suitable deck to allow rainwater runoff. 3- Preventing lateral washout of the internal mixture by sealing the interstices between the non-squared stone blocks with the same lime mortar used for beautification.

Numerical evaluations (Coulomb-Mohr model), permitted to determine coesion and internal friction parameters of the walls, to extimate the safety factor respect to seismic risk.

## SHEAR STRENGTH OF TUFF-MASONRY WALLS RETROFITTED WITH CFRCM – ID 1437

*C. Faella, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Martinelli, Dept. of Civil Engineering, University of Salerno, Italy*
*S. Paciello, Dept. of Civil Engineering, University of Salerno, Italy*
*E. Nigro, D.A.P.S., University of Naples Federico II, Italy*

The use of fiber reinforced polymers (FRP) in structural strengthening represents an effective alternative to traditional techniques of structural retrofitting. Carbon and glass based composite materials are widely used for strengthening RC members; they are usually applied by means of organic adhesives (such as epoxy resins). On the contrary, special cement-based mortar as a matrix for carbon fibers results in a good mechanical compatibility with respect to the support, especially in the case of tuff-masonry structures. Such a solution has been recently conceived and is usually named Carbon-Fiber Reinforced Cement Matrix (CFRCM). This paper is just devoted to an experimental campaign carried out on tuff masonry walls strengthened by means of CFRCM to increase their shear strength. A series of masonry walls have been tested under diagonal compression at the Laboratory of Structures of the University of Salerno, according to the ASTM E519/81 standard, to determine the shear strength of tuff masonry walls before and after the strengthening intervention. Unreinforced walls and differently strengthened ones are tested to quantify the influence of various solutions on the failure load and mechanism. The experimental work emphasizes that, because of the weak mechanical characteristics of tuff masonry, the collapse of panels is usually caused by delamination of support throughout the interface between masonry and mortar matrix. Simplified formulations are also proposed to determine the maximum shear strength of reinforced walls; their accuracy is tested in comparison with both the experimental data obtained in the mentioned campaign and available in the scientific literature.

## STUDY OF SYSTEMS OF CONSTRUCTION IN THE TRADITIONAL AHMEDABAD HOUSES: QUERY IN EARTHQUAKE RESISTANCE – ID 1492

*N. Akbar, Center for Environmental Planning and Technology, India*

Aim: To study traditional construction of Ahmedabad in order to establish Capability of structures to resist earthquakes.

The walled city [old city] of Ahmedabad which came into being on east bank of Sabarmati River, houses structures using traditional techniques of construction. There are several lessons to be learnt in the systems of making the old city, from plan organization of streets to construction of individual houses. These are the very structures that have survived several natural calamities that devastated newer parts of the city and if the indigenous techniques of building are not studied vital information about how to build in Ahmedabad would be lost.

The grouping of houses into a pol is typical of Gujarat and especially of Ahmedabad. A pol is made of elementary rectangular units evolved linearly along the street (parallel wall grouping system) with minimum surface area towards the street. These units are narrow, deep and consist of two bodies with courtyard in between and linked up by passage ways. The general rule in making of these units is that the rear body is higher than the body looking on to the street. The walled city buildings have a specific manner of construction using brick and wood placed in dense street formation giving an opportunity to study structural systems for earthquake resistance in Ahmedabad.

This structural behavior of the pol would help clarify the yet unclear understanding of structural systems in traditional construction of Ahmedabad.

The quest of this study is to find out whether these traditional structural systems provide a greater degree of resistance to earthquakes. The idealized modeling of alternative interpretations of behavior and 3D simulation techniques for analysis, will clarify the role of different materials and their construction systems within a structure.

## SEISMIC BEHAVIOUR OF TALL WOOD-FRAME WALLS – ID 1500

*M. Popovski, Forintek Canada Corp., Canada*
*A. Peterson, University of British Columbia, Canada*
*H. Prion, University of British Columbia, Canada*

Tall wood-frame walls up to 10 m in height are slowly emerging as a viable alternative to the tilt-up concrete and masonry box-type of non-residential construction in North America. Very little research has been undertaken to investigate the seismic performance of tall wood-frame walls. Consequently, design methods for such systems in various jurisdictions of North America are either non-existent or are extrapolated from those of regular size shearwalls used mostly in residential construction. Experimental and analytical research work is therefore needed to quantify the seismic performance of tall walls and develop some preliminary design guidelines for such structural systems.

The paper summarizes findings of a joint research project on the seismic performance of tall wood-frame walls. Results are presented from a series of quasi-static tests on 4.9 m by 4.9 m shearwalls subjected to axial and cyclic lateral loading. Tall walls with a variety of stiffness of sheathing-to-stud connections, stud materials, stud spacing, stud-to-plate connections, sheathing material, and sheathing thickness, were included in the test program. The influence of all these parameters on the strength, stiffness, and ductility properties of the tall wood-frame walls are discussed. The results of the experimental program have been used to develop and verify analytical models later used in a series of non-linear dynamic analyses to further investigate the behaviour of tall walls under seismic loads. Based on the research findings, some suggestions for design of tall walls are proposed.

## IMPROVEMENT OF MATERIAL PROPERTIES FOR PERFORATED CLAY UNITS IN GERMAN SEISMIC AREAS – ID 1506

*U. Meyer, Arge Mauerziegel, Germany*

*D. Schermer, Institut für Massivbau, Germany*
*M. Roßbach, Institut für Ziegelforschung, Germany*

The paper presents first results of the EU-sponsored research projects ESECMaSE (Enhanced safety and efficient construction of Masonry Structures in Europe). The material composition and the perforation pattern of typical clay units for loadbearing walls were optimised. The alterations resulted in a significant increase of the material resistance. First shear tests on walls are currently in progress and will soon allow an evaluation of the influence of the alterations on the shear loadbearing capacity of masonry walls (which will be given in the full paper). The results will form a basis for a new european design method for masonry shear walls.

## EXPERIMENTAL INVESTIGATION ON MASONRY ELEMENTS UNDER NORMAL STRESS AND SHEAR – ID 1510

*D. Liberatore, DiSGG, Italy*
*G. Spera, DiSGG, Italy*
*C. Tancredi, DiSGG, Italy*
*D. Nigro, DiSGG, Italy*

The use of macro-elements for the analysis of unreinforced brick masonry structures under seismic actions requires their preliminary calibration, based on micro-models accounting for the mechanical properties of bricks, mortar and brick-mortar interface under normal stress and shear. To this end, an extensive experimental investigation has been accomplished, consisting of tests on mortars, triplets, couples and modules. Two types of brick, solid and hollow, and six types of mortar, including cement, lime, lime-and-cement and hydrated lime mortars have been tested. Mortar specimens underwent three-point bending test, indirect tension tests and compression test. A high degree of correlation was found between the strengths coming from the three types of test. Tensile strengths in three-point bending and in indirect tension are equal, on the average, to 1/4 and 1/8, respectively, of the compression strength. A set of 36 triplets, with different combinations of brick and mortar types, underwent compression test. Failure occurred because of sub-vertical cracking of solid bricks, or spalling of hollow bricks. The strength of triplets with solid bricks is nearly double of those with hollow bricks. A set of 120 couples underwent shear-compression test, yielding cohesion, residual friction and dilatancy of the brick-mortar interface. A set of 24 modules (small panels of size approximately 40x40x12 cm3) underwent compression tests, along the directions normal and parallel to bed joints. The failure in compression normal to bed joints is similar to triplets. The strength of the modules with solid bricks is more than double than those with hollow bricks. The failure in compression test parallel to bed joints showed a recurrent pattern, consisting of cracks in bed joints and separation of the different courses.

## OUT-OF-PLANE CAPACITY OF HISTORICAL MASONRY DEPENDING ON ITS INTERNAL STRUCTURE – ID 1522

*C. Baggio, University Roma Tre - Department of Structures, Italy*
*G. De Felice, University Roma Tre - Department of Structures, Italy*

The out-of-plane seismic behavior of historical masonry depends on the quality of masonry work: historical masonry often owes its stability to the skilled arrangement of masonry units according to the rules of masonry construction. In the absence of interlocking, the shear forces that develop during rocking motion may lead to a premature collapse since the wall does not behave monolithically and tends to separate into two faces. In this case the capacity, expressed in terms of sustainable rotation, decreases significantly. However, the quality of masonry work, which depends on dimension, arrangement and interlocking of block units, not on a strength parameter, is not easy to assess.

The aim of this work is to evaluate the decrease of rotation capacity, with progressive lack of interlocking. To this end, in a first step, masonry walls made by the superposition of rigid units arranged together in regular patterns are analysed. Then, more complex assembly derived from the survey of masonry sections in historical centres are modelled. For each wall, the load-rotation capacity curve and the corresponding collapse mechanism are computed using Distinct Element Method.

## SEISMIC RISK MITIGATION OF HISTORICAL MASONRY STRUCTURES – ID 1546

*C. Syrmakezis, NTUA, Greece*
*A. Antonopoulos, NTUA, Greece*
*O. Mavrouli, NTUA, Greece*

The Mediterranean area along with its richness and diversity of historical structures is characterized by high seismicity. Local materials have mainly permitted the construction of masonry structures either made of natural or artificial building stones. Modern intervention requirements include functional and structural aspects and should be in accordance with the basic principles of reversibility, unobtrusiveness and respect of the original state of the structure. Within these terms, the application of passive control systems is investigated, for the rehabilitation of masonry structures. Damper devices can modify positively the structural response of these historical structures, under dynamic earthquake loading, by affecting their stiffness, ductility and overall strength. For their application, masonry's high stiffness and the subsequent need of large energy dissipation for small displacements should be considered. In this paper, achieved seismic vulnerability reduction is demonstrated though three case studies. The seismic response of the selected existing historical masonry structures is investigated. Namely, a Minaret, a Byzantine church and a curved arch bridge are analyzed. All three structures are representative of their class. The Minaret is a very flexible structure due to its great ratio of the height to the base. Alternatively, the Byzantine church demonstrates a complex bearing system of high overall stiffness, with a lot of architectural particularities (e.g. domes, vaults). The arch bridge has a total curve span of 116,00m and a height of 20,00m and railway service loads are applied on it. In all cases, damper devices are introduced for the improvement of the seismic performance and comparative analytic results are used to reveal the seismic vulnerability reduction achieved. Applicability limits are investigated and relative conclusions are drawn.

## DURABILITY OF MASONRY STRUCTURES UNDER SEISMIC ACTIONS – ID 1573

*R. Sofronie, Ecoland, Romania*

The paper deals with both, original masonry based on solid bricks with lime mortars and modern masonry based on cored bricks with cement mortars, also called mascrete. Both types of masonry are manually produced with the aid of gravity and behave excellent under gravitational actions. When earthquakes occur structural members of masonry and mascrete differently respond. To fix the ideas the principal mechanical characteristics of the two types of masonry are first comparatively discussed. The influence of seismic actions is also included in discussion. The durability of masonry structures is regarded as a probabilistic concept which defines the span of time when, under any state of loading, no damages or faults occur. This is why the paper suggests using for durability the Mathematical Theory of Reliability what is in accordance with the provisions of ISO 13822:2001. In that case for structures with normal service the durability is expressed with the aid of MTBF as a nonlinear function of the risk index. By focusing on seismic risk indices the durability of masonry structures can be accordingly evaluated. On the other side with the aid of appropriate reliability schemes the proposed approach of durability is able to describe the global behaviour of structures under different combinations of loading, the seismic ones including. That means it has a holistic character, and with the aid of reliability schemes the durability of structures can be controlled. Due to the strong pressure of some advanced technologies the masonry structures are now in a critical position. The purpose of this paper is to offer a new and practical tool when the dilemma between masonry

and mascrete in seismic areas arises. It may be used either for evaluation the seismic risk of existing buildings or for the seismic design of new buildings.

### BEHAVIOUR OF AN UNREINFORCED MASONRY BUILDING SUBJECTED TO HORIZONTAL COMPONENTS OF BAM EARTHQUAKE – ID 1582

*K. Pourazin, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iran (Islamic Republic Of)*

Seismic behaviour of buildings during past earthquakes has shown that unreinforced masonry buildings are more seismically vulnerable than reinforced masonry buildings or masonry buildings with horizontal and vertical ties. This paper makes an effort to evaluate the effects of walls thickness and roof beams direction on seismic behaviour of a typical one-storyed unreinforced masonry building in elastic range. For this purpose, multicomponent response spectrum analysis approaches like CQC3 and SRSS are implemented. Two horizontal components of Bam-Iran earthquake (December 26, 2003) which were recorded in the near field are used as seismic input. Based on the obtained results, some guidelines are recommended to reduce vulnerability of unreinforced masonry buildings.

### THE CHARACTERISTIC DAMAGES OF MASONRY BUILDINGS AND THEIR RECONSTRUCTION METHODS – ID 1600

*M. Hrachya, National Survey for seismic Protection, Armenia*

Historical and apartment houses are widespread in Armenia made of natural stone ? tuff. In consequence of the earthquake in 1988, these buildings got serious damages. Most of them had been reconstructed and reinforced. We studied the reasons and damage characters of stone constructions as well as multiple methods of their reinforcement and reconstruction, which had been applied by different specialists, constructors. The reconstruction methods of buildings without evaquation of inhabitants is also brought forth in the report. We defined the criteria of reinforcement level and estimate the privileges and shortcomings of each reconstruction method in technical, practical and economical aspects, on the basis of dynamic characteristics, measurement of buildings before and after the reinforcement. The catalogue is already compiled for practical use, where different types of reconstruction methods of masonry buildings are concentrated.

### DRILLING DOFS OF MEMBRANE ELEMENTS IN 2D IN-PLANE ANALYSIS OF HISTORICAL STRUCTURES – ID 1655

*A. Mena, KOERI, Bogazici University, Turkey*
*Y. M. Fahjan, KOERI, Bogazici University, Turkey*

Membrane elements with drilling degrees of freedom are of great practical interest, since they provide a possibility for constructing a fully compatible model of a complex structural system in which they appear combined with beam elements. Since the addition of drilling rotations to membrane elements has been a difficult task, involving complex formulation, its effect in the membrane formulation must be assessed. The membrane element has gained accuracy with the addition of incompatible displacement modes, in both geometrically linear and nonlinear formulations. In this study, theories of membrane elements for linear and nonlinear analyses have been implemented by developing homemade MatLab codes. The membrane formulations are employed to accommodate a suitable plasticity model. The plane stress element formulation with incompatible modes is implemented as well. The effect of DOFs and incompatible modes in the membrane formulation is investigated through the finite element modeling of two cross sections of historical structures. Linear and nonlinear static as well as time history analyses are carried out.

### DESIGN DETAILING FOR TIMBER STRUCTURES IN SEISMIC ZONES – ID 1691

*E. Fournely, LGC-CUST, France*
*T. Lamadon, BUREAU VERITAS, France*

In earthquake design process, design detailing is always an essential step. This aspect is much more important for timber structures due to the fact that dissipative zones are located in joints. Design detailing is only evocated in standards and only few documents are available to present such detailing. In France, AFPS, French Association for Earthquake Engineering, begun three years ago a working group action on this aim with Mario Gianquinto as animator. The result of this WG action is a complete book on steel, concrete, masonry and timber buildings. The objective of this paper is to present the global and local analysis used to define details integrating earthquake resistant disposals for different types of timber structures for European practise and standards. Ductility classes, diaphragms and regularity criteria are discussed. Examples of glulam frames, traditional carpentry or trussed rafters exhibit this investigation and some results.

### BEHAVIOUR OF UNREINFORCED MASONRY STRUCTURES – ID 2074

*D. Schermer, TU Munich, Germany*

To investigate the behaviour of unreinforced masonry (URM) constructions under seismic loading full-scale pseudo-dynamic tests have been carried out. The tested structure has been reduced to a symmetric and plane 3-DOF system. The tests were carried out just on the relevant shear wall in the first story under combined vertical and horizontal loadings. The upper two stories of the structure with the shear-walls and their restraint in the concrete slabs considered numerically modeled as a sub-structure. Its stiffness characteristics in the shape of nonlinear bending- and shear-springs were determined within preceding static-cyclic tests. The evaluation of the results focused on the stiffness and load reduction. It can be concluded that unreinforced masonry structures show a significantly better behaviour under seismic loadings than determined by current codes.

## ES 3h: Structural Engineering - Miscellaneous

Level-1

### COMPARATIVE ANALYSIS OF SEISMIC RESPONSE OF ALUMINIUM ALLOY AND STEEL ELEMENTS AND STRUCTURES – ID 81

*V. Vukasinovic, Energoinvest, Bosnia And Herzegowina*
*G. Necevska-Cvetanovska, IZIIS-Skopje, Macedonia*
*D. Kozinakov, Mechanical Faculty, Macedonia*

In this paper from the analytical aspect, comparative behavior of different aluminium alloy and steel structural elements and structures are treated: simple beam, arch, truss, space frame structure and cupola, subjected to static and also to dynamics (earthquake) loads. All national standards and codes limits the maximal deflections for the elements exposed to bending depending on their span, and having in mind that aluminiums designing procedure starts from the serviceability limit states due to low modulus of elasticity, for all elements in this analysis, starting condition was equality of deflections. Aluminium is strong and ductile material but also lighter compared to steel, so excited mass during the earthquakes will be considerable smaller with less induced inertia forces. Among great number of results here will be presented just some comparative diagrams of time histories of displacements, velocities, accelerations, moments and axial forces.

### FUNDAMENTALS OF OPTIMUM PERFORMANCE-BASED SEISMIC DESIGN – ID 100

*H. Moghaddam, Sharif University of Technology, Iran (Islamic Republic Of)*
*I. Hajirasouliha, Sharif University of Technologh, Iran (Islamic Republic Of)*

This paper presents a new method for optimization of dynamic response of structures subjected to seismic excitation. This method is based on the concept of uniform distribution of deformation. In order to obtain the optimum distribution of structural properties, an iterative optimization procedure has been adopted. In this approach, the structural properties are modified so that inefficient material is gradually shifted from strong to weak areas of a structure. This process is continued until a state of uniform deformation is achieved. It is shown that in general for a MDOF structure there exists a specific pattern for distribution of structural properties that results in an optimum seismic performance. It has been shown that the seismic performance of such a structure is optimal, and behaves generally better than those designed by conventional methods. The application of the proposed method for optimum seismic design of different structural forms such as truss-like structures and shear buildings is presented. Effects of fundamental period, target ductility demand, damping ratio and seismic excitations on optimum distribution pattern are investigated.

### VIBRATION BASED SEISMIC DAMAGE RECONSTRUCTION OF A R/C STRUCTURE – ID 127

*S. Kokot, Opole University of Technology, Poland*
*Z. Zembaty, Opole University of Technology, Poland*

After a strong earthquake it is of great importance to asses damages of structures as fast as possible and eventually to decide about their future exploitation or repair. Very often such damages can not be directly inspected and require in-direct methods of their assessment (e.g. structures covered with architectural elements, floors etc.). The so called Structural Health Monitoring dealing with these problems (see e.g. Balageas et al. 2006) it is actually a vast field of research providing in many cases near on-line monitoring of structural damages usually aiming at detecting localized damage or damages. These methods however are often not appropriate for reinforced concrete structures displaying distributed damages at any level of seismic load (see e.g. Bolton et. al 2005, Zembaty et al. 2006). The purpose of the paper proposed for the 1st ECEES it is to present a method of damage reconstruction for a two-span beam. The damages are characterized by loss of stiffness distributed along the beam with the EJ stiffness reduction from about 5% to 40%. Using harmonic excitations the method makes it possible not only to detect damage but to accurately reconstruct the actual damage distribution along the beam. So it provides practical means for post-earthquake damage assessments. A detailed numerical example will be presented during the Conference References BOLTON R., SIKORSKY C., PARK S., CHOI S., STUBBS N., Modal property changes of a seismically damaged concrete bridge, Journal of Bridge Engineering, ASCE, vol 10, 2005, pp.415-428 BALAGEAS, FRITZEN, GUEMES, eds., Structural Health Monitoring, iSTE, Hermes Science, London 2006, pp.1-426. ZEMBATY Z., KOWALSKI M., POSPISIL S., Dynamic identification of a reinforced concrete frame in progressive states of damage, Engineering Structures, vol.28, no.5, 2006, pp.668-681.

### TECHNICAL AND ECONOMICAL EVALUATION BETWEEN CONCRETE AND STEEL COOLING TOWERS – ID 231

*K. Fallahi, MAPNA Co., Iran (Islamic Republic Of)*

Cooling systems are one of the most requirements for industrial countries which have power plants, oil industries, gas, petrochemical and process industry, these systems are very important for heat system complements and processing aspect. Now so many researches around the world search all the aspects of these systems. Cooling systems will be selected according to economic, technique, possibility, ecology of area and environmental rules. Without considering to thermodynamic in cooling systems, from the aspect of structural system they are made in two difference shapes: - Concrete shell cooling towers - Steel structure cooling towers These two types of cooling systems are made in different countries that in comparison to each other have some advantages and disadvantages choosing to use them are performed by considering to economic, executive technical and erecting technology.

Recently due to the growth of engineer's technical know- how in the destructive effect of earthquake on the installations and other constructions specially the most important ones "Life Line", advantaged into development and enhanced the use of light weight structures in countries mostly frequented by earthquake like Japan. This has also become subject of several discussions in our country over choosing any of these two elements in the cooling towers of Power Plant projects. "Iran Power Plant Projects Management Co.(MAPNA) " as the greatest EPC contractor company which produces thermal power plant in Iran and middle east search completely on both steel and concrete options with special condition in difference site condition for two combine cycle power plant in Khoy and Mashad cities in Iran. This paper tried to generally discuss the advantages, disadvantages and limitations of each, to present as a basic principle for this comparison between them.

### PROBABILISTIC RELIABILITY ASSESSMENT OF SEISMIC ISOLATION AND SEISMIC PROTECTION SYSTEMS – ID 257

*J. Albert, The B.E. Vedeneev VNIIG, Inc., Russian Federation*

There are abundant variants of seismic isolation and seismic protection of objects of different purpose that are known today. Design-theoretical investigations of such systems in most cases are aimed at determining its effectiveness implying the degree of inertial loads and objects deformability lowering. However, another significant factor of effectiveness is the safety of these systems. In various fields of industrial and civil engineering reliability evaluation usually carries out through calculations based on deterministic formulation that implies availability of quite determined given data: action characteristics, parameters of considered system and so on. On the basis of calculation results the working capacity of systems under specified loads can be defined. This technique has several drawbacks: in the first place it lacks quantitative reliability assessment and therefore doesn't allow comparing several variants of seismic isolation and seismic protection systems; in the second place, averaged empiric coefficients obtained based on analysis of available on-site data are used in considering of randomicity of seismic load and determining strength, deformative and dissipative characteristics of system and object itself. The present article describes reliability evaluation procedure, which is based upon a probabilistic approach and allows receiving a numerical reliability assessment of practically any seismic isolation and seismic protection systems, including considerably nonlinear ones. The procedure is based upon a synthesis of parametrical and structural reliability theory of complex multiple-unit systems. As an illustrative example there are shown a reliability calculation of "Construction - seismically isolated foundation" system with a seismic load given as an elementary function with a random amplitude and frequency.

### NUMERICAL STUDY OF SINGLE STORY BUILDING CONSTRUCTED USING 3D-PANEL PREFABRICATED SYSTEM UNDER SEISMIC MOTIONS – ID 272

*M. Kabir, Amirkabir University, Iran (Islamic Republic Of)*

In this paper, the numerical dynamic behavior of 3D wall single-storey building, which is constructed by 3D system, is described. 3D wall panels are used in construction of exterior and interior bearing and non-load bearing walls and floors of building of all types of construction. This system consists of a welded wire space frame integrated with a polystyrene insulation core. The wall panel is placed in position and wythes of concrete are applied

to both sides. Wall panel receives its strength and rigidity by the diagonal cross wires welded to the welded-wire fabric on each side. This combination produces a truss behavior, which provides rigidity and shear terms for full composite behavior. Speeds in construction, weight lightening and thermal insulation are the marked privileges for building built up with such innovative system. In numerical analysis, the model of the building is analyzed under traditional ground motions both in high frequencies and low frequencies nature in order to verify the safety of the system. ANSYS as a powerful non linear finite element software is adopted for numerical modeling and analysis. Shell element is selected for modeling of 3D panel in both system and component levels. Objectives of the study are to obtain seismic performances of the described structural system under dynamic loading, such as linear and non-linear structural characteristics, hysteretic behavior, deformability and stiffness degradation. By this study, structural responses such as the seismic damage mechanics and the seismic capacity, the distribution of earthquake forces are evaluated. In linear analysis, the primary frequencies, vibration modes and comparison of the results are obtained. Also, the lateral deformations, story drift, torsion of system, are calculated numerically in time domain and are compared with each other.

## THE INELASTIC RESPONSE DIFFERENCES OF TWO BUILDINGS DESIGNED WITH DIFFERENT SEISMIC BEHAVIOR FACTORS – ID 615

*J. A. Avila, National University of Mexico (UNAM), Mexico*
*E. Morales, National University of Mexico (UNAM), Mexico*

The elastic and inelastic responses of step-by-step dynamic analysis of two reinforced concrete buildings of 9 and 17 levels (offices), located in the Old Lake zone, designed according to Mexico City Code with the seismic behavior factors (similar to ductility factors) Q= 1, 2, 3 and 4 and the permissible drift of 0.012, facing important earthquake, with and without the available over-resistance effects are checked. For the designs, spectral modal dynamic analysis are made, based on the limit states of service and failure conditions; for Q= 1 and 2 the general requirements of Reinforced Concrete Norms are used and for Q= 3 y 4 the ductile frames requirements are checked.

For the step-by-step inelastic analysis different typical accelerograms for soft soil are considered. The non-linear responses in history time, local and global, without (conventional design) and with the over-resistance effects are calculated, and they are compared against the Code admissible values. By studying the inelastic seismic analysis for the different kinds of resistances, with the over-resistance effects the responses reduce very important. This is, estimating the inelastic seismic responses with the nominal resistances, the non-linear behavior could be over-estimated such global as local.

## A DETAILED STUDY OF THE SEISMIC RESPONSE OF A LARGE ELECTROSTATIC PRECIPITATOR – ID 704

*E. Cruz, P. Universidad Catolica de Chile, Chile*
*D. Valdivia, P. Universidad Catolica de Chile, Chile*

The seismic response of a large electrostatic precipitator obtained from a model based on a finite element representation of the equipment and the steel support structure, including a special representation of the interior components of the system that are hanging is carried out.

The behavior of the casing is represented by a combination of "frame" elements for the ribs and frames and "shell" elements for the casing itself both in the longitudinal direction (air/gas flow direction) and in the transverse direction. For the internal components, "frames" and "shell" elements are also used, as appropriate to the geometry and characteristics of the components. The mass distributions are obtained from the geometric description of the components considering the different materials. "Added mass" is considered to represent the weight of the dust in the collector plates. The support conditions of the internal elements are modeled using "springs" and nonlinear link elements ("gap") with properties that represent their mechanical behavior including the possible pounding of hanging elements against the casing or internal beams.

The support structure is modeled using "frame" elements and "hinges" according to the actual configuration of the attachment of the equipment to the support structure.

The earthquake action is represented by actual ground motion records from different sites where rather extensive earthquake induced damage were observed. Different types of events are considered (near fault records, subduction zone records).

The results of the analyses for different earthquake ground motions are discussed in terms of overall system behavior, internal parts behavior, and maximum loads acting on the support structure and the foundation. The values obtained from an equivalent static analysis are also compared in terms of support reactions (foundations), values of global forces (base shear) and displacements in some key points of the system (equipment-support structure).

## VIBRATION CHARACTERISTICS OF BUILDINGS USING MICROTREMOR MEASUREMENTS – ID 708

*J. Kanai, Akita Prefectural University, Japan*
*K. Tokeshi, Akita Prefectural University, Japan*
*C. Cuadra, Akita Prefectural University, Japan*
*M. Karkee, Akita Prefectural University, Japan*

The estimation of the dynamic characteristics of one SRC 6-story building using microtremor measurements was performed. The dimensions of the building are approximately 31m width (NS direction) x 67m length (EW direction), and 38m height. Two horizontal sensors were set in each of 3 observation points (one at the middle and two at the sides along EW direction) on the 1st story and the 6th story, respectively. Simultaneous synchronized time microtremor records during 600s with 100Hz sampling frequency were obtained at all observation points. Only one clear predominant frequency in the Fourier amplitude spectrum was obtained in the NS direction, which would correspond to its normal mode. However, three and two predominant frequencies along the EW direction were obtained in the Fourier amplitude spectrum of the sides and the middle observation points, respectively. In case of the Fourier spectrum from side observation points, the three predominant frequencies would correspond to the normal, torsional and bending modes, as well as, the two predominant frequencies in the Fourier amplitude spectrum of the middle observation point would correspond to the normal and bending modes. The torsional and bending modes usually can not be obtained in two-dimensional mode analysis, and a three dimensional analysis using finite element method was needed to verify the estimated dynamic characteristics of this building. Additionally, these dynamic behaviors estimated from microtremor measurements were verified in one microvibration from one aftershock of the 2004 Mid Niigata Earthquake, measured at one of the side observation point in the 6th story.

## WAVELET ANALYSIS IN DYNAMIC IDENTIFICATION OF BASE ISOLATED BUILDINGS: APPLICATION TO THE SOLARINO BUILDINGS – ID 774

*G. Oliveto, Italy*
*G. Scalia, Italy*

The wavelet transform is a tool that divides data, functions or operators into different frequency components and then studies each component with a resolution matched to its scale. Forerunners of this technique were produced independently in pure mathematics in 1964, physics in 1968 and 1985 and engineering in 1977 and 1986; for references to these see Daubechies (1992). Applications to the analysis of seismic data were advocated by Morlet (1982), while an early example of wavelet analysis on a building base isolated against underground rail traffic excitations is provided by Newland (1993). These days the technique is mathematically well established and finds widespread applications in many fields. This paper presents recent work on the dynamic identification using wavelets of the mechanical properties of a four storey reinforced concrete building seismically retrofitted by base isolation, Oliveto 2004, 2006. After briefly introducing wavelet decomposition, the

paper presents additional results to those given by Oliveto 2006. These include structural damping evaluated from inter-storey drifts, and drift accelerations, velocities and displacements at the design displacement level and below. The drifts are also split into the isolation mode and main structural mode components, showing the relative importance of each component. It is expected that further results will be found before full paper submission which will also be included.

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## STRUCTURAL SYSTEM IDENTIFICATION BY USING HILBERT TRANSFORM – ID 808

*L. L. Hong, National Cheng Kung University, Taiwan*
*B. Huang, National Cheng Kung University, Taiwan*

It is important to realize the instantaneous parametric information in linear time-varying and nonlinear systems for the structural health monitoring purpose. When a Hilbert transform is performed to the equations of motion, an additional set of equations is obtained and then is combined with the original equations to estimate the time histories of dynamic properties. The fundamental assumption in this method is the slow variation of dynamic properties. Several SDOF and MDOF structures simulating linear time-invariant, time-varying and nonlinear systems excited by the ground motions of the 1999 Chi-Chi earthquake are used to validate this parametric identification technique. For the linear time-invariant systems, it is shown that the identified parameters are indeed the same as the exact ones when the floor acceleration, velocity, and displacement are all assumed to be recorded. Once the floor velocity and displacement are integrated numerically from the floor acceleration record, the relative errors in the stiffness and damping coefficients are less than 0.1% and 0.2%, respectively. In general, the identified parameters in the strong-motion state are most accurate among those in the whole time history. The same accuracy in the identified parameters is also observed for the linear time-varying and nonlinear systems, except some abruptly enlarged errors occurred in the state of degrading stiffness. Those errors come from the overlapping frequency content of the system parameters and the system responses and could be reduced by other numerical manipulation.

## SEISMIC RESPONSE OF DOUBLE HINGED ARTICULATED LATTICE TOWER – ID 908

*N. Islam, Jamia Millia Islamia, India*

Present study investigates the seismic response of double hinged articulated tower vis a-vis single hinged articulated tower, in the presence of waves. An articilated tower is one of the compliant latticed steel tower, made up of tubular pipes equipped with upright buoyancy chambers flexibily linked to the sea floor through a hinge. Above sea water level it supports a deck, for the purpose of various operations in offshore oil drilling.The seismic response of the tower has been carried out in time domain by an spectral analysis, the method is based on the principle of random vibration where seismic excitation is assumed to be a broad band stationary process. using this assumption the mean peak response of the tower is obtained from the ground acceleration time history of the earthquake process. The non-linear equation of motion is derived by Lagrangian approach and the solution is obtained by newmark's B intgration scheme.The response of double hinged tower are compared with single hinged tower. A parametric study is carried out to highlight the relative importance of earthquake load in comparision to wave loading. The result shows that the seismic response investigation is quite crucial for the design of hinges, if the tower is located in seismically active zone.

## ENHANCED STIFFNESS-MASS RATIOS METHOD FOR DAMAGE DETECTION IN BUILDINGS WITHOUT BASELINE MODAL INFORMATION – ID 1036

*R. Rodríguez, Instituto de Ingeniería-UNAM, Mexico*
*J. A. Escobar, Instituto de Ingeniería-UNAM, Mexico*
*R. Gomez, Instituto de Ingeniería-UNAM, Mexico*

In this paper, the enhanced stiffness-mass ratios method, ES-MRM, to calculate the undamaged state of buildings with shear or flexural-beam behaviour is presented. This method utilizes modal information from the damaged state of the structure and the first storey lateral stiffness value of the structure without damage to determine its baseline modal information.

In order to localize and calculate damage magnitude, the determined undamaged or baseline state of the structure is compared with the damaged one. Damage is defined in terms of loss of stiffness.

It is demonstrated that the ES-MRM produces exact results for buildings with constant stiffness-mass ratios distribution at every storey. Several case studies are presented and discussed and the feasibility of the method to detect damage in buildings, when baseline modal parameters are not available, is corroborated.

## SOFT COMPUTING BASED RELIABILITY-BASED OPTIMIZATION OF REAL WORLD STRUCTURES UNDER SEISMIC LOADS – ID 1109

*Y. Tsompanakis, Technical University of Crete, Greece*
*N. Lagaros, National Technical University, Greece*
*M. Fragiadakis, National Technical University, Greece*
*M. Papadrakakis, National Technical University, Greece*

Modern earthquake engineering design philosophy has introduced the concept of performance-based design for structures subjected to seismic loading conditions. Furthermore, seismic structural design requires an effective way to treat the inherent probabilistic nature of geometry, material properties and loading conditions. Reliability-Based Optimization (RBO) of structures is perhaps the only viable procedure to assess whether the structural design under investigation meets the required performance targets with the best possible way under a probabilistic viewpoint. However, the computational cost for optimizing large-scale structural systems considering uncertainties is orders of magnitude higher than in the case of a conventional seismic design, especially when, as in the present study, a non-linear analysis method is employed in order to evaluate the inelastic behavior of the structure. In this paper a robust and efficient methodology is presented for performing RBO of space steel frames under seismic loading. The proposed methodology combines efficient structural optimization (using Evolution Strategies (ES) optimizer) and reliability analysis procedures (employing Monte Carlo Simulations (MCS) incorporating Latin Hypercube Sampling). In order to reduce the excessive computational cost and make the whole procedure applicable for real-life engineering applications appropriately tailored Artificial Neural Networks (ANN) is incorporated in the proposed methodology. The use of ANN was motivated by the time-consuming repeated analyses required by the MCS in the reliability analysis phase and by the ES evolutionary optimization algorithm during the optimization process. In both cases a properly trained ANN is used for the fast computation of the necessary data, thus avoiding expensive dynamic structural analyses. The proposed methodology has been applied in sizing structural optimization problems of large-scale three-dimensional steel frames.

## BEHAVIOR OF REINFORCED CONCRETE BEAMS WITH CARBON FIBERS (CFRP) – ID 1191

*R. Proaño, Earthquake Research Center - CISMID, Peru*

In response to the growing necessity of repairing or rehabilitation of reinforced concrete structures, new technologies of structural reinforcement have been developed. Among those the polymers reinforced with carbon fibers of high resistance (CFRP) are a real alternative for the industry of construction.

The engineers that attempt today the use of CFRP in applications of external reinforcement are in the challenge of the innovation. At the moment do not exist clear rules for the design of RC elements (beams or columns) reinforced with CFRP. The American Concrete Institute (ACI) committee 440-F have developed a document (ACI 440F-99,1999) to provide design recommendations and technical construction of the CFRP in reinforced concrete elements, where it is defined an explicit methodology for appropriate use of security factors, low ductility, anchorages, adhesive, etc. With regard to this, it is provided some conservative limits in the design philosophy used and the values of reliability of the material.

However, in seismic zones, the ductility of structural reinforced members and the ultimate resistance should be calculated in order to know the performance of the structures.

The main objective of this document is to try to describe the behavior of the RC elements reinforced with CFRP through the moment-bend diagrams corresponding to compound section (concrete-steel-CFRP) subjected to bending. It is also shown, the mathematical formulation to obtain these diagrams.

## INSTANTANEOUS IDENTIFICATION OF SYSTEMS WITH HYSTERESIS UN-DER SEISMIC LOADING – ID 1261

*P. Argoul, LAMI-ENPC, France*
*R. Ceravolo, Politecnico di Torino, Italy*
*G. V. Demarie, Politecnico di Torino, Italy*
*S. Erlicher, LAMI-ENPC, France*

During their lifecycle structures may undergo actions, such as wind or earthquake, that can supply the structure with enough energy to activate a pronounced non-linear behav-iour. Special signal processing tools are needed for extracting reliable informations from transient response signals. At this regard, time-frequency analysis has recently offered new perspectives, and its efficacy in non-linear identification may be enhanced by assigning it a role in the framework of Volterra series representation [1]. An alternative approach is based on non-linear auto-regressive models. Structural elements, under seismic loading, show a typical hysteretic behaviour that in this study has been expressed through modified Bouc-Wen models [2]. Classical methods for the identification of such models would pursue a parametric approach. The proposed paper, instead, attempts to define proper instantaneous indicators of hysteretic behaviours. There exists an extensive literature about the techniques for identifying Volterra sys-tems (e.g. see [3]), but most methods require the calculation of higher order statistical mo-ments: in structural engineering applications it is not possible to obtain a number of experi-mental measurements large enough as necessary to get a consistent estimate of all the statis-tical moments needed, especially when the dynamic tests are conducted in situ. The avail-ability of a limited number of experimental data can be obviated to a certain extent by taking into account the "localisation" in time of the frequency content of the signals, through the time-frequency representation of the signals and the definition of instantaneous estimators of the mechanical properties to be identified [1].

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## MATERIALS' VARIABILITY INFLUENCE ON SEISMIC PERFORMANCE OF PARTIAL-STRENGTH COMPOSITE JOINTS – ID 1275

*M. Badalassi, Dept. of Structural Engineering University of Pisa, Italy*
*A. Braconi, Dept. of Structural Engineering University of Pisa, Italy*
*W. Salvatore, Dept. of Structural Engineering University of Pisa, Italy*

The seismic design of moment-resisting steel-concrete frames allows the dissipation of seismic energy localising plasticizations in the beam-to-column joints, that should be partial-strength regarding beams concurring in the joint, offering the ability to adapt seismic-design resistance to the expected demands. European research projects have been conducted to investigate the behaviour of composite, partial-strength, beam-to-column joints under seismic actions, involving the execution of experimental tests on substructures and a full scale model, and the development of mechanical models to define the seismic behaviour of composite steel-concrete joints. Results obtained so far indicate that component method proposed by Eurocode4 for designing composite joints under static actions should be modified to consider complex phenomena occurring in such joints during an earthquake. Furthermore, ductile behaviour and adequate rotational capacity required for composite joints by Eurocode8 could be guaranteed by establishing a strength-hierarchy amongst the various resistant elements transmitting forces from beams to columns, so that the ductile components alone govern the joint's functioning. In this perspective, material resistance variations play a primary role: ductile behaviour of a joint is influenced by materials' resistance, which determine the joint components' hierarchy. This paper describes a study on the influence of materials strength variability on ductile performances of a specific type of composite joint. To this end, a mechanical model, developed by component approach, is applied. Materials' properties randomness is considered using MonteCarlo simulation method optimized with importance sampling technique. The focus is on the effects of the over-strength properties of modern steel and concrete's strength variations on joint behaviour, in terms of ductile or brittle failure. Furthermore, we seek a reasonable range of variability in material resistance that can guarantees the efficient seismic behaviour of such joints (ductile failure and adequate rotational capacity) to guarantee an overall ductile behaviour for the frame.

## DYNAMIC BEHAVIOR OF SHIELD TUNNEL IN TRANSVERSE DIRECTION – ID 1359

*K. Mizuno, East Japan Railway Company, Japan*
*A. Koizumi, Waseda University, Japan*

This paper describes the dynamic behavior and the seismic design method of shield tunnel in transverse direction considering the effect of staggered jointed rings. A series of shaking table model tests and two kinds of analyses were carried out. To model the structural properties of staggered segmental rings, the decline in bending rigidity due to the transverse joints and the transmission of shearing force due to the circumferential joints were considered in both the test models and the analytical models. In the tests, a double-track subway shield tunnel was considered as a prototype, and materials of ground and tunnel were chosen according to the similarity law. In the analyses, the dynamic 2-D FEM and the static analysis based on seismic deformation method using beam-spring model were employed. To grasp dynamic characteristics of ground and tunnel, the numerical simulations by 2-D FEM were carried out. In the analyses using beam-spring model, the time when the maximum relative displacement between top and bottom of the tunnel occurred was focused. The conclusions from this study are as follows: (1) The shield tunnel has much flexibility and follows the surrounding ground during the earthquake event. (2) The dynamic 2-D FEM analysis explains the dynamic behavior of the ground in significant accuracy. However, from the viewpoint of the seismic design method of shield tunnels, this analytical method should be improved more with regard to evaluating the effects of staggered jointed rings. (3) Analytical results of sectional forces obtained from the static analysis based on seismic deformation method using beam-spring model almost explained the test values. Especially, the effect of transverse and circumferential joints can be evaluated sufficiently. Therefore, this analytical method can be suggested useful for the seismic design of shield tunnels in transverse direction.

### EFFECTIVE USE OF EARTHQUAKE RESPONSE FOR SYSTEM IDENTIFICATION OF TORSIONALLY COUPLED BUILDINGS – ID 1548

*G. Hegde, Indian Institute of Technology Bombay, India*
*R. Sinha, Indian Institute of Technology Bombay, India*

System identification plays an important role in health and condition monitoring of buildings. To identify damage in a structure the frequencies and other modal parameters are often calculated from the dynamic measurements, and then an inference about the damage is made. The modal parameters can be extracted from the response of structure to free and forced vibrations. The identification of frequencies and damping of torsionally coupled system is difficult since the structural system possess closely-spaced frequencies. In this paper, three mode identification methods, Complex Exponential Algorithm, Ibrahim Time Domain Method, and Eigen Realization Algorithm are evaluated for their effectiveness in estimating the modal properties of torsionally coupled building subjected to base excitations. A new mode shapes interpolation method is devised to extract mode shapes of torsionally coupled system from modal data of only top and lowest floor. The limitations of the above identification methods are examined by using example multi-storey torsionally coupled buildings.

### REINFORCED CONCRETE STRUCTURES DESIGN IN SEISMIC AREAS: LESSONS LEARNED FROM RECENT EARTHQUAKES IN INDIA – ID 1606

*V. Kumar, NATIONAL INSTITUTE OF TECHNOLOGY, JAMSHEDPUR, IND, India*

India has a very high frequency of great earthquakes (magnitude greater than 8.0). Moderate earthquakes create awareness and lead to improvements in construction at a low human cost. This has led to complacence in Indian earthquake preparedness. India now have orders of magnitude, higher levels of man-made construction and a significantly larger population than what India had at the time of great earthquakes of 1897, 1934 or 1950; hence, India are now more vulnerable to earthquake disasters. India has had a number of the world's greatest earthquakes in the last century. In fact, a more than 50 percent area in the country is considered prone to damaging earthquakes. India is prone to damaging earthquakes as clearly illustrated by the Koyna (1967), the Lature (1993) and the Jabalpur (1997) earthquakes. This paper attempts to provide an overall perspective of past Indian and the interesting behaviour of R.C structures during the same. The earthquake resistant design and construction of building has been in active practice for the past three decades. Hence the behaviour of R.C buildings is critically dependent on their design, detailing and construction. The present paper highlights some of the basic features of building damage/collapse and discusses their deficiencies. The failures with RC buildings may be classified into either the failures due to building structures partly or wholly and failures due to soil conditions. There has been an inadequacy on at least one of the four main attributes desired of an aseismic building such as good structural configuration, adequate stiffness, minimum strength and good ductility. Earthquake damage to buildings consists of the most effective lessons on aseismic construction. For buildings a database with different categories may not be effective, as each structure is unique and has to be considered as a problem on its own.

### DESIGN OF THE SUBSTRUCTURE OF THE VANCOUVER CONVENTION CENTRE – ID 1634

*J. Robertson, Westmar Consultants Inc., Canada*
*H. Kullman, Westmar Consultants Inc., Canada*
*R. MacPherson, Westmar Consultants Inc., Canada*
*M. Cowdell, Westmar Consultants Inc., Canada*

The Vancouver Convention Centre substructure consists of a pile supported concrete deck, 45,000 square metres in area constructed on a congested site on the Vancouver waterfront. The deck structure extends northward from the existing shoreline, so that the north section of the structure is entirely over water while the southerly portion of the deck is located onshore . As most of the area is overlain by liquefiable sediments, and old fills, the seismic design of this structure present unique challenges to the designer. Non-linear behaviour of the subsoils, variable support conditions for the piles across the structure, and discontinuities in lateral load path from the superstructure to the deck all contribute to increased uncertainty with respect to the seismic response of the structure.

This paper presents an overview of the design criteria and methodology employed in the seismic analysis and design of the substructure. The seismic analysis incorporated a non-linear finite difference FLAC analysis to assess soil structure interaction. A non-linear pile analysis was also employed to develop a more accurate assessment of the behaviour of the piles under seismic conditions. While the design was predicated on limiting deformations of the structure under the design earthquake, a three dimensional modal dynamic analysis was also carried out on the substructure to ensure that account was taken of torsional effects, higher modes, and the eccentricity inherent in these designs. Extensive ground improvements were also required to control liquefaction and to reduce deformations to acceptable levels.

### EFFECTS OF REGIONAL VARIATIONS IN MODELING EARTHQUAKE VULNERABILITY FOR KEY BUILDING TYPES IN ITALY AND CENTRAL EUROPE – ID 2023

*A. Baca, Risk Management Solutions, United States*
*P. Seneviratna, Risk Management Solutions, United States*
*C. Williams, Risk Management Solutions, United States*
*T. Onur, Risk Management Solutions, United States*
*M. Nyst, Risk Management Solutions, United States*

The distribution of seismic hazard through Central Europe and the Mediterranean region varies as greatly as the cultural and built environment. It is therefore interesting to compare the earthquake risk in countries with historically low seismicity such as Switzerland and Germany to the more tectonically active Italy. Any damage or loss estimation study must account for unique characteristics in seismic hazard and vulnerability at both the national and regional levels. As part of modeling earthquake losses throughout Italy and Central Europe, vulnerability relationships were developed for specific building types and geographic regions. This study presents the effects of regional building inventory and performance on loss estimates. Comparisons are made between structures in multiple countries including Italy, Germany and Switzerland as well as between varying types of construction and occupancy. The source modeling and ground motion components of this project are discussed in separate presentations (Nyst et al., Onur et al., 2006, to be presented in this conference). Building damage has been estimated with a spectral-response based methodology. The concluding portion of this study is to calibrate modeled losses using data from historic events. For the key vulnerability classes modeled, there is a strong agreement between predicted and actual loss.

## ES 4: Design Criteria and Methods, Codes
Level-1

### ECONOMY THROUGH PERFORMANCE SEISMIC DESIGN OF STEEL BUILDING FRAMEWORKS – ID 2

*J. Douglas, BRGM, France*
*P. Prasad, IIT, India*
*M. Shrikhande, IIT, India*
*P. Agrawal, IIT, India*

The recent past earthquakes, Northridge and Kobe are witness that how the economy of the well design steel buildings

for single performance levels have the central focus of the seismic resistant design in spite of very high life safety due to unacceptable damages. Multi-performance level seismic design was strongly realized in immediate practice because even the developed economy of USA and Japan did not accept such a large damages. Economy is the major attribute to be considered as one of the seismic design objective under the influence of the varying earthquake ground motions, which is popularly known as Performance-Based Seismic Design (PBSD). The role of steel frameworks as reliable structural systems has been praiseworthy during so may earthquakes except Northridge and Kobe hence needs more fundamental researches that the design objectives of PBSD may be achieved. This paper considers the overall view of economy aspect of PBSD in more logical manner balancing functionality, safety and serviceability of steel building frameworks. For such achievement various aspects have been searched to localize the sequence of fail-safe design aspects so that the damage portion may be economically assessed and repaired. Locations of columns, spacing between beams, shear span depth ratio, type of floor systems, types of the structural systems and types of the bracing systems have been searched for developing economy for earthquake resistant parameters. Some software's have been used as and where required for finding expected economy of the seismic design as the goal of this paper. An emphasis has been made for column hinging with limited ductility as the major concern of limited damage hence the overall economy due to high life cycle cost of the steel building frameworks under the attack of varying earthquake ground motions.

## DISPLACEMENT-BASED SEISMIC DESIGN OF STRUCTURES WITH SIGNIFICANT HIGHER MODE CONTRIBUTION – ID 37

*J. Humar, Carleton University, Canada*
*M. Ghorbanie-Asl, Carleton University, Canada*
*F. Pina, Carleton University, Canada*

A practical method for the displacement based seismic design of buildings where higher modes make significant contribution to the response is presented, with particular reference to the design of reinforced concrete shear wall buildings.

For preliminary design, approximate estimates of the yield and ultimate displacements are obtained, the former from simple empirical relations, and the latter to satisfy code specified limits. The structure is converted to an equivalent single-degree-of-freedom system using an assumed deformation shape that is representative of the first mode. The required base shear strength of the SDOF system is determined from the inelastic demand spectrum corresponding to the ductility capacity or the ratio of the ultimate to the yield displacement. The structure is designed for the moments produced by the estimated shears.

The frequencies and mode shapes of the structure are now determined and a pushover analysis is performed using a force distribution that follows the first mode. This gives refined estimates of the yield and acceptable ultimate displacements. The latter must be selected so as to: (1) limit nonstructural damage, (2) ensure stability under P-Delta effects, and (3) keep the ductility demand within ductility capacity. A new equivalent SDOF system is developed using the first mode deformation shape and revised shear strength and moment resistance demands are calculated.

The moment resistance and displacements obtained from first mode assumption are expected to reasonable estimates of the demand. However, the shear strength demand is likely to be inaccurate because the higher modes make substantial contribution to the base shear. A multi-mode pushover analysis is therefore carried out to find more accurate estimates of the shear demand.

It is shown that drift limits imposed to mitigate nonstructural damage and to avoid P-Delta instability often govern the design and the ductility capacities specified in the present codes are rarely utilized.

## CRITICAL REVIEW OF CODE PROVISIONS FOR ESTIMATION OF PROBABLE FLEXURAL STRENGTH OF R/C BEAMS – ID 43

*C. Aydemir, Yildiz Technical Univercity, Turkey*
*M. S. Kircil, Yildiz Technical Univercity, Turkey*
*M. Eser, Yildiz Technical Univercity, Turkey*
*M. Zorbozan, Yildiz Technical Univercity, Turkey*

Capacity design procedure is an essential part of earthquake resistant design of ductile R/C structures. It is an effective tool to keep the potential damage under control and to provide an adequate energy dissipating capacity to structural elements. According to many design codes, shear design of R/C beams are made based on the shear demand corresponding to probable flexural strength of beam sections so that strength enhancement, caused by actual material strength, strain hardening of reinforcing steel and additional compression reinforcement can be considered. All relevant codes recommend simple methods to estimate the probable flexural strength of beams. In this study, considering the uncertainty in material strength and realistic material models, the accuracy of requirements of Eurocode 8 and Turkish seismic design code have been investigated. The compressive strength of concrete, the ultimate strain of concrete, the yield strength of reinforcing steel, the ultimate strain of reinforcement steel, beam width and effective depth of beam are considered as random variables. Latin hypercube method was used for the generation of sample values of selected random variables. A total of 15120 moment-curvature analyses have been performed. Finally, probable flexural strengths determined with code provisions are compared to the maximum moment capacities extracted from moment-curvature analyses. Results show that code provisions are not accurate enough to take all the source of strength enhancement into consideration. Using a constant factor, regardless of tension reinforcement ratio and the ratio between tension and compression reinforcement, to estimate the probable flexural strength of beams is not effective enough.

## APPLICATION OF BASE ISOLATION SYSTEM TO A LARGE HOSPITAL BUILDING – ID 48

*L. Di Sarno, University of Sannio, Italy*

The structural control of vibrations may be achieved by modifying masses, stiffness and damping, and allowing passive or active counter forces to be generated. Innovative passive, active and/or semi-active protection strategies have been rapidly adopted in Asia, Europe and the US, where several approaches have been assessed, optimized and used successfully in practical applications. The present paper focuses on the application of base isolation (BI) to a large hospital to be built in Naples, in South of Italy, in a region of medium seismicity. The plan layout of the building is about 144x144m and the total height is about 29m. The structural system utilized for the superstructure is a RC multi-storey framed system. The latter exhibits a large mass eccentricity because of the different height (3 and 8 storeys, respectively) of the two L-shape blocks of the superstructure. The fundamental period of vibration of the fixed base frame is relatively high, i.e. 1.23 sec; the horizontal flexibility of the superstructure apparently reduces the beneficial effects of BI. Nevertheless, the case study demonstrates that BI is an effective strategy to improve the seismic performance also for relatively flexible framed structures both at serviceability and ultimate limit states. The isolation system employed comprises about 600 circular-shaped high damping rubber bearings with different diameters (600mm, 800mm and 1000mm in diameter). The design of the sample BI structure is the first application of the new national (Ordinanza Ministeriale) and European seismic standards (EC8) for a large irregular hospital building in Europe. Architectural and engineering aspects, including both civil and mechanical works, are discussed in details. The solutions adopted for the case study are also be compared to design solutions utilised for other similar projects world-wide. An extensive parametric analysis of the structural system is presented in order to validate the design solutions adopted.

## BRACING SYSTEMS FOR SEISMIC RETROFITTING OF STEEL FRAMES – ID 49

*L. Di Sarno, University of Sannio, Italy*

The present analytical study assesses the seismic perfor-

mance of steel MRFs retrofitted with different bracing systems such as ordinary diagonal braces, unbounded braces and mega-braces. The latter utilise braces connecting two or more storeys and are located on the facades and/or internal frames. The reliability of design rules provided in international codes and recommendations for CBFs is also reviewed. Benefits, if any, of alternative bracing systems, e.g. unbounded and mega-braces, are discussed. Medium rise steel MRFs have been designed with lateral stiffness that does not fulfil the code drift limitations. Hence, the sample frames have been retrofitted with ordinary diagonal braces, unbounded braces and mega-braces. To provide consistent comparisons, the alternative configurations of bracings have been designed with the same elastic lateral stiffness. The seismic performance of such structures has been investigated through inelastic static (pushover) and dynamic (response-history) analyses. Near- and far-field records at different hazard levels have been utilised in non linear time history analyses carried out. The structural performance has been assessed in terms of global parameters, e.g. storey shears, system over-strength, storey drifts, roof translation ductility and hysteretic energy. The results of the analyses carried out demonstrate that structures with unbounded braces perform better than ordinary diagonal braces under seismic loads. Significant reduction of maximum storey shears and drifts as well as enhanced energy dissipation capacity were found for mega-braces.

### A COMPARATIVE STUDY OF SEISMIC ISOLATION CODES WORLDWIDE—PART I. DESIGN SPECTRUM— – ID 63

*D. Feng, Fujita Corp., Japan*
*W. Liu, Guangzhou Univ., China*
*K. Masuda, Fujita Corp., Japan*

After the 1994 Northridge earthquake, the 1995 Hyogoken-Nanbu earthquake and the 1999 Chi-Chi earthquake, the number of seismically isolated buildings has increased rapidly. Over the same period, building codes have been revised and updated to include requirements for design of seismically isolated buildings. A test study is presented in order to understand and illustrate the differences in the isolation provisions of the building codes of Japan, China, the USA, Italy and Taiwan. The concept of the design spectrum in each code is summarized first. To consider the seismic region coefficients, the target construction sites are assumed to be in Tokyo, Beijing, Los Angeles, Potenza and Taipei, respectively. A fixed soil profile is assumed in all cases, where the average shear wave velocity within the top 30m is about 209 m/s. The code spectra with 5 percent critical damping are calculated to compare the seismic load level at each location. In the short period range, less than about 0.5s, Sa,Italy is the largest. For periods longer than about 0.6s, Sa,USA and Sa,Japan have approximately the same value. Beyond about 1.2s, Sa,Taiwan has the largest value, due to the Taipei basin geology. The code spectra with 20 percent critical damping are compared continually, which dominant the response of a seismically isolated building in extreme earthquakes. The increase in damping results in Sa,Italy and Sa,USA with the largest ordinates in the short period range, and Sa,Taiwan and Sa,China largest in the long period range. For periods longer than about 3.2s, the Sa,China has the largest values of all five codes. The response reduction factor due to the damping factor and the decreasing rate in the long-period spectrum which are considered to be related with the characteristics of ground motions are discussed at last.

### A COMPARATIVE STUDY OF SEISMIC ISOLATION CODES WORLDWIDE—PART II. RESPONSE ANALYSIS— – ID 66

*W. Liu, Guangzhou Univ., China*
*D. Feng, Fujita Corp., Japan*
*K. Masuda, Fujita Corp., Japan*

Following Part II, the procedures to do response analysis of a seismically isolated building are summarized based on the building codes of Japan, China, the USA, Italy and Taiwan. While a dynamic response analysis method is recommended in all five building codes, a simplified design procedure based on equivalent linear analysis is also permitted under limited conditions. The main limitations are summarized as follows. A construction site class is limited to hard soil conditions, except in the Italian code. The maximum height of the superstructure is limited, except in the Taiwanese code. In the Japanese and Chinese codes, the limitation on the height of the target building is more relaxed. Thus the target buildings capable to adopt isolation technologies extended widely. No tension is allowed in the isolation devices, except in the USA code. Subsequently, a typical 14-story reinforced concrete building, isolated with lead-rubber bearings is analyzed using each of the five building codes. The building's characteristics such as weight, height, hysteresis properties and soil condition are fixed in all cases. The properties of the LRB isolation devices are also kept constant, with a total yield force for the isolation system of four percent of the total weight. In the time history analysis methods, ten synthetic ground motions are used which are fitted to the design spectrum of each of the five codes in the frequency domain. There are eight random phases and two real earthquake record phases obtained from the 1940 El Centro NS and 1968 Hachinohe NS components. The average response values are taken as design values to compare with the results by the equivalent linear analysis method. The deformation of the isolation level and the base shear force coefficient of the superstructure are compared.

### PERFORMANCE BASED DESIGN USING FORCE REDUCTION AND DISPLACEMENT AMPLIFICATION FACTORS FOR RCMRF – ID 68

*M. Mahmoudi, Sari Technical College, Iran (Islamic Republic Of)*

Force based design method will be soon replaced by performance design method in new seismic codes. In performance based design, the hazard levels and relevant acceptable damages are clearly specified. Structural and non-structural performances are controlled by limiting stiffness, strength and members ductility characteristics. It needs inelastic analysis to be done on structural model with primary structural characteristics (stiffness and strength) which are unknown at the beginning of design. In this paper a method will be proposed for determination of the primary stiffness and strength demands needed for inelastic analysis for R/C moment resisting frames using displacement amplification factors (Cd) and force reduction factors (Rw) related to hazard levels. It means that three force reduction factors and three displacement amplification factors are determined and introduced for minor, moderate and major earthquake levels (or three structural performances controls; Immediately Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP)) for determination of primary stiffness and strength demands. Force reduction factors depend on force reduction factor due to ductility (R$\mu$), overstrength factor (Rs) and safety factor (Y). Displacement amplification factors depend on ductility factor ($\mu$), overstrength factor (Rs) and safety factor (Y). R$\mu$, Rs and $\mu$ depend on structural performance (IO, LS and CP). The procedure for determination of Rw and Cd factors will be presented in this paper. The results show that force reduction factors (Rw) and displacement amplification factors (Cd) can be used in performance based design to determine the primary stiffness and strength demands.

Keywords: performance based design, force reduction factors, displacement amplification factors, R/C moment resisting frames, immediately occupancy, life safety, collapse prevention.

### MORE RATIONAL CRITERIA FOR DESIGN EARTHQUAKE FORCES – ID 101

*I. Hajirasouliha, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. Moghaddam, Sharif University of Technology, Iran (Islamic Republic Of)*

The preliminary design of most buildings is based on equivalent static forces specified by the governing building code. The height wise distribution of these static forces seems to be based implicitly on the elastic vibration modes. Therefore, the employment of such a load pattern in seismic design of normal

structures does not guarantee the optimum use of materials. This paper presents a new method for optimization of dynamic response of structures subjected to seismic excitation. This method is based on the concept of uniform distribution of deformation. In order to obtain the optimum distribution of structural properties, an iterative optimization procedure has been adopted. In this approach, the structural properties are modified so that inefficient material is gradually shifted from strong to weak areas of a structure. This process is continued until a state of uniform deformation is achieved. It is shown that the seismic performance of such a structure is optimal, and behaves generally better than those designed by conventional methods. By conducting this algorithm on shear-building models with various dynamic characteristics subjected to 15 earthquake ground motions, more adequate load patterns are introduced with respect to the period of the structure and the target ductility demand.

### SEISMIC EVALUATION OF EXISTING STEEL CONCENTRIC BRACING BUILDINGS, BASED ON FEMA 356 – ID 115

*F. Danesh, K.N.Toosi University, Iran (Islamic Republic Of)*
*F. Amiri, K.N.Toosi University, Iran (Islamic Republic Of)*

In this paper, seismic behaviour of steel structures with concentric braced frames (X shape) is evaluated. For this purpose, three buildings with 4, 10, and 16 storey that were designed by valid codes in IRAN (Iranian code of practice, 2800) are selected. We use FEMA criteria for this evaluation. 3-Dimension models of these structures were analyzed under the Nonlinear Static Procedure. Columns, beams and braces were modeled using parameters for nonlinear procedure that indicate in FEMA 356. In this investigating, two levels of earthquake hazard such as BSE-1 and BSE-2 or Maximum considered earthquake (MCE) were selected. In these analysis, the effective fundamental period (Te), the response spectrum acceleration (Sa), many coefficient like C0,C1,C2,C3 and then target displacement that are given by 3-15 Equations in FEMA 356, were calculated. In addition, two load patterns are used for lateral displacement distribution. The first pattern is a vertical distribution proportional to the story shear distribution calculated by combining modal responses from a response spectrum analysis of the building. The second pattern is a uniform distribution consisting of lateral forces at each level proportional to the total mass at each level. The SAP2000 computer program is used for these analyses.

The analytical results indicate that in 10 and 16 storey buildings in BSE-1level, in bottom stories, the columns that are carried the additional axial forces transferring from bracing elements, are force-controlled members and then are failed before the bracing elements go to inelastic range. Compression bracing elements in bottom stories in BSE-1, are also enable to permit other ductile elements absorb energy.

### A CRITICAL LOOK ABOUT PENALTY ON THE RESTRICTION OF THE HEIGHT OF RC FRAME STRUCTURE DESIGNED BY ALGERIAN CODE RPA99/VER. 2003 BY USING THE CAPACITY SPECTRUM METHOD (CSM) – ID 140

*F. Bakhti, CGS, Algeria*
*S. A. Zermout, CGS, Algeria*
*M. Inukai, NILIM, Japan*
*Y. Mehani, CGS, Algeria*
*T. Azuhata, NILIM, Japan*
*T. Saito, IISEE, Japan*

The main scope of this paper is to criticize the issued of the chapter (3.4-A-1) in the RPA99/Ver.2003 which restrict the high of the RC frame structures. For this purpose, a seismic performance evaluation technique by Capacity Spectrum Method (CSM) is applied to typical RC frame buildings designed by Algerian code RPA99/Ver.2003. The Japanese Code BSL2004 is used to evaluate the seismic capacity of the RC frame structures. Pushover analysis method is adopted in order to obtain the performance curve of those existing buildings using a three dimensional nonlinear program CANNY and Nonlinear Time History Analysis is also performed using accelerograms of Zemmouri 2003 (Algeria) and El–Centro 1940 (USA) for verification. It is shown that the chapter (3.4-A-1) of the RPA99/Ver.2003 is too much disadvantageous in the restriction of the RC frame structures height.

### A SIMPLE PROCEDURE FOR THE ASSESSMENT OF SEISMIC DRIFT RESPONSE OF BUILDING STRUCTURES LOCATED IN SEISMICALLY ACTIVE AND NEAR-FAULT REGIONS – ID 141

*B. Ozturk, Nigde University, Turkey*

This study focuses on the development of a simple procedure for the assessment of seismic drift response of building structures located in seismically active and near-fault regions. Pointing to the displacement-based design approach which correlates observed damage of a structure according to its drift ratio; the behavior of the nonlinear displacement displacement response of building structures are investigated on the basis of the ground velocity change, DV. Nonlinear displacement spectra are defined for single-degree-of-freedom systems. The study presented mainly focuses on Marmara Earthquake of August 17th., 1999 and Duzce Earthquake of November 12th., 1999. The effects of T, DV, Cy and Tg are investigated on the nonlinear displacement demand; where T stands for the building period, Cy is the base shear strength coefficient and Tg is the characteristic period of the ground motion.

### A NEW APPROACH FOR THE DEVELOPMENT OF A NONLINEAR DISPLACEMENT RESPONSE SPECTRA IN TURKEY – ID 142

*B. Ozturk, Nigde University, Turkey*

This study concentrates on the development of a nonlinear displacement response spectra in Turkey. It is based on the investigation of the concept of ground velocity change, DV and its effects on the nonlinear displacement response of single-degree-of-freedom (SDOF) systems. The ground motion data recorded in Turkey during both Marmara Earthquake (August 17th., 1999) and Duzce Earthquake (November 12th. , 1999) provided the basis for this study. It is observed that the increase in the ground velocity change, DV increases the nonlinear displacement response of the system. Regarding the Displacement-Based Design Approach; this situation refers to increased damage. Accordingly; the results are compared with respect to the displacement response methodology described by Lepage (1997). Nonlinear displacement spectra are defined, considering the effects of base shear strength on the behavior of SDOF systems.

### VERIFICATION OF CODE COMBINATION RULES FOR MAXIMUM COLUMN REINFORCEMENT – ID 174

*G. Ozmen, Istanbul Technical University, Turkey*
*E. Orakdogen, Istanbul Technical University, Turkey*
*K. Darilmaz, Istanbul Technical University, Turkey*

In seismic design of structures, seismic excitations are usually applied along two orthogonal axes. However, it is well known that, other critical angles of excitation exist which maximize structural response for certain response quantities. This fact is demonstrated by SRSS and CQC approaches, which are developed by several authors. These approaches provide sound solutions to determine maximum structural response for certain quantities, such as bending moments, displacements etc. However, The SRSS and CQC techniques fail to furnish the appropriate loading combination for maximum reinforcement for RC columns, which are under the effect of biaxial bending moments. On the other hand, in contemporary earthquake-resistant design codes, a percentage rule for the design of structural elements are given. The purpose of this study is to determine the maximum column reinforcements by means of a parametric investigation and to verify the results

obtained by the percentage rule. A number of non-orthogonal sample structures are chosen and subjected to lateral loading in parametrically varied directions. Maximum reinforcement for each column is calculated and compared with the results obtained by the code formulae. Various combination coefficients are tested and the results are discussed. It is concluded that, the percentage rule existing in certain design codes seems to provide fairly satisfactory results for practical purposes. However, they may be considered as being slightly on the unsafe side.

### ESTIMATING COMBINATION COEFFICIENTS FOR PERFORMANCE BASED DESIGNING (PBD) – ID 190

*O. Sakharov, Saint-Petersburg Transport University, Russian Federation*
*I. Kuznetsova, Saint-Petersburg Transport University, Russian Federation*
*A. Uzdin, Saint-Petersburg Transport University, Russian Federation*

It is traditionally considered, that seismic loads have small repeatability and are not to be taken into account together with other loads. PBD radically changes the approach to seismic loads accounting. PBD requires structures calculation for both rare strong earthquakes and for more frequent weak ones. In the latter case it is necessary to combine seismic loads with others, for example, with wind, transport, ice and other loads. Three main goals are considered in the paper 1. Combination of seismic and other loads for a single construction. 2. Combination of seismic and other loads for a group of structures. 3. Combination of seismic and mobile loads for an extended structure. Estimating the factor of combinations is based on constructing equiprobable pairs « seismic load - combined load ». To build such pairs, some limiting condition, for example, breakdown of normal operation is to be accepted. For this condition the allowable probability of its occurrence [P] is set. Using this probability a set of the above mentioned equiprobable pairs is considered. The structure under consideration is calculated for each pair using the given limiting condition and the most dangerous pair is to be selected for designing the structure. Some examples of combining the seismic load with the temperature, wind and mobile railway loads are considered in the paper. The temperature load is taken into account in estimating the travel of movable bearings of bridges. Factors of combinations are estimated for designing a big railway bridge across the Nevelskoy strait (Sakhalin) and for a bridge across the river Amu-Darya in Turkmenia. Combinations of wind and seismic loads are considered in designing towers of cellular communication in Irkutsk region in Russia.

### THE STATE NORMS: CONSTRUCTION IN SEISMIC REGIONS OF UKRAINE – ID 243

*Y. Nemchynov, NIISK, Ukraine*
*P. Kryvosheyev, NIISK, Ukraine*

The basic regulations of the project of national norms of Ukraine DBN B.1.1-...-2005 "Construction in seismic regions of Ukraine" are submitted in the paper. The project was prepared taking into account the basic regulations of SNiP II-7-81* and the requirements of code of European countries and Norms of Commonwealth of Independent States (CIS) counties for earthquake engineering. Development of new maps of general seismic zoning (GSZ) was performed by IGPh of National Academy of Sciences of Ukraine and Crimean Advisory Committee on Seismic Hazard Assessment and Earthquake Prediction. The set includes the lot of maps: 1. Maps of GSZ: A; B; C for the whole territory of Ukraine on a scale 1:2500000. 2. Detailed maps of GSZ: A0; A; B; C for territories of AR of Crimea and Odessa region on a scale 1:1000000. Design seismic loads on the structures should be determined by two methods: spectral one and with using of direct dynamic calculation on earthquake accelerograms. Direct dynamic calculation method is applied to buildings and structures with fundamentally new structural solutions, and also buildings with height more than 50 m and large-span structures with spans more than 30 m. In regions with high seismicity (8 and 9 points) the height of buildings with steel frame is limited correspondently by 12 and 16 stories. The height of buildings from reinforced concrete constructions is permissible to be not more than 9 stories at site design seismicity equaled 9 points. Buildings of above-mentioned stories are related to the objects of experimental construction. The order of design and construction of such buildings is regulated by special directives of Minstroy of Ukraine

### DISPLACEMENT- BASED DESIGN APPROACH FOR DESIGN OF RC FRAME BUILDING STRUCTURES – ID 296

*G. Necevska-Cvetanovska, IZIIS, University Ss. Cyril and Methodius, Macedonia*
*R. Petrusevska-Apostolska, IZIIS University Ss. Cyril and Methodius, Macedonia*

Seismic design is currently based on force rather than displacement. However, the experience from the recent earthquakes has shown that strict application of existing seismic design codes enables protection of human lives, but at the same time, the structures may suffer damage that is either non-repairable or too costly to be repaired.

Having in mind that damage to structures is directly related to their displacement demand, more importance has been given to displacement. Modern trends in earthquake engineering show that there is a common consensus that the new design methodologies should be performance-based. In this direction, the concept of the so called "Performance-Based Seismic Engineering, (P-B SE)" provides a corresponding framework for development of new trends of seismic design.

Within the frames of the P-B SE, different displacement-based approaches for engineering evaluation and design have been proposed by the researchers. Their fundamental goal is to obtain a structure, which will reach a predetermined displacement when subjected to an earthquake consistent with the design level event.

A direct displacement-based procedure for seismic design of RC building structures will be presented in the paper. This design procedure uses the Substitute Structure Approach by which an inelastic system is modeled as an equivalent elastic system whose stiffness and damping are equivalent to those of an inelastic system. The substitute structure has the same ultimate force and ultimate displacement characteristics as the inelastic structure. Therefore, the substitute structure approach allows an inelastic system to be designed and analyzed by using elastic displacement response spectra. Based on the defined target displacement, the base shear demand is calculated and a structural design to resists this demand is performed. The next step is application of the capacity design approach and checking of the structural behaviour by nonlinear static analysis. The design is corrected, if necessary.

### DESIGN OF R.C. BUILDINGS FOR DIFFERENT DUCTILITY CLASSES ACCORDING TO THE NEW EC8 – ID 380

*M. Hrasnica, Faculty of Civil Engineering University Sarajevo, Bosnia And Herzegowina*
*S. Medic, Faculty of Civil Engineering University Sarajevo, Bosnia And Herzegowina*
*N. Begic, Faculty of Civil Engineering University Sarajevo, Bosnia And Herzegowina*

Earthquake resistant concrete building should possess energy dissipation capacity. This is achieved by adequate resistance and ductility of structural elements. New draft of EC8 allows design for low ductility by applying only the rules of EC2 for the seismic design situation. Design for higher ductility classes, medium and high ductility, comprises application of specific earthquake resistant provisions of capacity design method. The aim is to develop stable energy dissipation mechanism in structure under repeated reversed loading due to earthquake and to avoid any kind of brittle failure in the structure. Three most implemented structural types of multistory concrete buildings were analyzed: ductile wall system, frame system and dual system made of frames and walls. They were exposed to different levels of seismic loading, represented by

PGA of 0.10, 0.20 and 0.35 g. The buildings were designed for low, medium and high ductility, taking into account the rules and recommendation from EC8. Design results for different ductility classes and seismic intensity were compared. Applying medium and high ductility gives opportunity to reduced base seismic shear significantly, resulting in considerable reduction of longitudinal reinforcement, especially for high ductility class, compared to natural ductility of reinforced concrete structures designed only according to EC2. However, to achieve suitable plastic mechanism and to avoid brittle failure in the structure, a great amount of special reinforcement details and various requirements have to be fulfilled. The amount of transverse reinforcement, built in mainly due to increased shear forces and to ensure local ductility grows also significantly, especially for high ductility level. The longitudinal reinforcement in columns must be increased to achieve well-known principle: strong column-weak beams, in order to have desired plastic mechanism. The total reinforcement quantity does not decrease in some cases with higher ductility classes, as expected.

### DIFFERENT METHODS OF ANALYSING MODELS OF THE SAME STRUCTURE USING EC8-1 – ID 385

*S. Lu, Arsenal Research, Austria*
*R. Flesch, Arsenal Research, Austria*

This Paper will describe an analysis of a 5 storey reinforced concrete structure in according to EC8-1, where different analysis methods for the same structure were used and compared to each other to point out the differences.

The structure was investigated with the following methods:

- 3-D Finite Element analysis, performed by ANSYS - Lumped Mass Model with response spectra analysis - Simple model in according to EC8-1

The analysis was performed in according to EC8-1, where the results are compared to each other and furthermore the difference between the results will be discussed.

This paper will show the advantage and disadvantage of the different analysing methods, to give an overview and a decision base, how sophisticated the model should be chosen for a serious earthquake design.

### TRANSFORMATION OF VULNERABILITY CURVES BETWEEN REGIONS WITH DIFFERENT ANTISEISMIC CODES – ID 401

*N. Nanos, Structural Mechanics, UK*
*A. Elenas, Structural Mechanics & Earthquake Engineering, Greece*

The lack of adequate seismic records in countries with limited or inexistent antiseismic funding allocation poses a great problem in the development of simulation tools that could enable scientists and civil authorities to create suitable damage mitigation programs using a realistic model that will describe the consequences of a major seismic excitation on a region's building stock. In contrast, other countries with advanced seismic content and major antiseismic funding allocation managed to create several advanced models for post earthquake damage estimation.

This paper presents a mathematical model that transforms the results based on ATC-13 and the US antiseismic provisions in order to be compatible with buildings designed using Greek antiseismic codes. At the beginning we have specified the most important characteristic parameters that define the differences between the U.S. and Greek building codes (UBC and EAK). The next step is the weighting of parameters in respect with the building's seismic response. After conducting an in-depth comparison of the two codes, a third one has been used as a calibration procedure. For this step the Italian building code (RSA) was used. The choice was made due to the fact that Italy has a rather adequate post earthquake damage data logging and subsequently a good set of vulnerability curves for various types of buildings. Therefore, starting with the vulnerability curves based on ATC-13 and by applying the present methodology vulnerability curves for buildings designed in accordance with the Greek antiseismic codes can be determined. The results of the methodology presented are vulnerability curves for regions with bad or non-existent seismic damage records based solely on building code provisions. The proposed method is successfully applied to a reinforced concrete frame building.

### ASSESSMENT OF IRREGULAR R/C FRAMES WITH MASONRY INFILL WALLS IN VIEW OF BGSC AND EC8 – ID 410

*E. Vaseva, CLSMEE-BAS, Bulgaria*

In EC8 the symmetry and regularity of earthquake resistant buildings are recommended. But in a lot of cases in the design practice these two requirements cannot be met. In many European and Balkan countries the common practice is to place masonry infill walls in the frames. These elements are usually disregarded in design according to the existing national codes. The special rules for taking into account the presence of infills – regular and irregular are included in EC8. In this paper the behaviour of frame with infill walls and the influence of frame irregularity in elevation on the seismic response are studied. Some recommendations as modification of the behaviour factor and some specific provisions on detailing of the local regions for building with vertical irregularity are given in EC8. Similar provisions are given in Bulgarian seismic code too. The effectiveness of these provisions has to be checked through a number of numerical and experimental analyses. The results from these analyses are shown. The methodology for modeling and analysis of R/C frame structures with infill masonry walls and for evaluation of the seismic damage parameters and the vulnerability functions of these types of structures has been elaborated. The methodology includes definition of damage indices, failure criteria and assessment of the behaviour coefficients on the basis of the vulnerability functions. Emphasis is given to the modeling of infill walls and the results using the generalized macro models are compared with these received form experimental tests. From the received results it is evident that the more important problem concerning the effects of infills is their distribution and the behaviour of the frames are direct functions of the maximum interstory drifts. In general the effect of the infills cannot be neglected in design.

### ENDURANCE TIME METHOD: A DYNAMIC PUSHOVER PROCEDURE FOR SEISMIC EVALUATION OF STRUCTURES – ID 443

*H. E. Estekanchi, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. T. Riahi, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Vafai, Sharif University of Technology, Iran (Islamic Republic Of)*

A dynamic pushover procedure for seismic evaluation of structures based on time-history analysis is presented. In this method, the structure is subjected to a gradually intensifying accelerogram and its performance is assessed based on the maximum time duration that it can meet the specified performance objectives. The concept of the Endurance Time (ET) method is somewhat analogous to the exercise test used by cardiologists for assessing cardiovascular status of heart patents. Standard intensifying accelerograms for ET analysis have been produced using numerical procedures and optimization techniques. The response spectrums of the generated accelerograms, while remaining proportional to a typical code specified design spectrum, intensify in a uniform manner with time. For quantitative comparisons, the accelerograms have been calibrated in such a way that their response spectrum for SDOF systems reaches the code specified level at a target time which has been set at ten seconds in this study. Induced accelerations and displacements increase linearly with time. It has been shown that by using the average of three accelerograms, acceptable convergence and accuracy can been achieved for linear SDOF and MDOF systems. Analysis results for MDOF systems are also shown to be consistent with modal analysis results. Maximum drift and base shear have been considered as basic design criteria. Consistency of the results with codified procedures has been discussed. The use of alternative design criteria and

damage indexes in determination of endurance time has also been explained. Application of the method in the nonlinear range has been presented by considering simple elastic perfect plastic models. Potential of ET method as an effective and versatile tool for performance based seismic analysis and design of structures has been discussed. Dynamic characteristics of these accelerograms are also discussed and compared with actual earthquake records.

### NONLINEAR PROCEDURES IN REVISED TURKISH CODE FOR SEISMIC PERFORMANCE ASSESSMENT AND RETROFIT DESIGN – ID 450

*M. N. Aydinoglu, Bogazici University, Turkey*

The Turkish seismic design code, which is effective since 1998, has been recently revised to include a new chapter on seismic performance assessment and retrofit design of existing buildings. In addition to traditional strength-based procedures, the new chapter follows the new trend in earthquake engineering practice and specifies methods and criteria allowing the seismic assessment to be made according to deformation-based approach, which effectively involves practice-oriented nonlinear analysis methods. Practice-oriented nonlinear analysis procedures contained in the revised code include single-mode pushover analysis methods based on invariant and adaptive load patterns as well as an improved pushover method based on Incremental Response Spectrum Analysis (IRSA) recently developed by the author. The latter is capable of handling multi-mode effects in three-dimensional pushover analysis of structures. The new chapter on seismic assessment and retrofit design follows a performance-based approach, in which ductile deformation demands and brittle force demands are estimated for multi-level earthquake actions. In this respect, 2% and 50% exceedence probabilities have been considered in defining new earthquake intensity levels in addition to standard 10% probability of exceedence in 50 years. Seismic demand quantities are then evaluated for various performance levels in accordance with deformation and internal force capacities defined in the code. In particular, deformation capacities have been specified for reinforced concrete elements in terms of permissible strain limits of concrete and reinforcing steel at section level. Practice-oriented nonlinear analysis procedures contained in the revised Turkish code (2006) are expected to attract considerable interest from both research and engineering communities at home and abroad towards the implementation of such procedures not only on existing buildings, but at the same time for the performance-based design of new structures in the near future.

### SEISMIC DEMANDS OF PLANAR R/C SYSTEMS USING PUSHOVER ANALYSIS – ID 526

*T. Makarios, Engineering Seismology & Earthquake Engineerin, Greece*
*H. Xenidis, A.U.Th, Greece*

In the present article, the pushover analysis correlated, on the one hand, the optimum equivalent non-linear single-degree-of-freedom (SDF) system that substitutes to general multistory planar reinforced concrete (r/c) system and on the other hand the known inelastic spectra, is presented. In order to estimate seismic demands at seismic performance levels (mainly at "life safety" and "collapse prevention"), the application for accuracy reasons of non-linear response history analysis (RHA) is suggested. However, due to high computational costs of RHA, civil engineers often prefer to use the static pushover procedure in order to estimate approximately the seismic demands of a general multistory plane r/c frames. Recently, the optimum equivalent non-linear SDF system that is suitable for the pushover analysis has been defined. Planar multistory r/c systems, which posses regularity in elevation, have been examined successfully using on the one hand the non-linear response history analysis for known corresponding strong ground motions and on the other hand the pushover analysis with the optimum equivalent SDF system and known corresponding inelastic spectra. Now, planar multistory r/c systems with irregularity in elevation are examined. The general conclusion is that, the optimum equivalent non-linear SDF system is suitable for all types of (regular or irregular) planar r/c systems in order to estimate approximately and quickly the seismic demands, while the accuracy of the seismic results is depended on the irregularity level of the examined system. Finally, a numerical example of irregular planar r/c 5-story system is presented.

### SEISMIC PERFORMANCE MANAGEMENT DESIGN OF BUILDINGS – ID 528

*E. Thorhallsson, Reykjavik University, Iceland*

This paper discusses how the system thinking concepts can be applied in performance based earthquake engineering. System thinking is a new type of methodology. Instead of focusing only on few design steps and prescribed design criteria from standards as done by conventional methods, should the designer take into consideration the whole life cycle of the buildings. By using system thinking concept in the design project working methods. All decisions in earthquake structural engineering are based on calculations and / or judgement given from designer's experience. The way that the design process goes can be illuminate as working in systematic way with "hard" systems, calculated conclusion and in "soft" systems, conclusions from judgement. The goal in system thinking is to refocus the design engineer to take all aspects of the structure into consideration. That implies the designer to valuate his design against other possibilities thought some kind of system hierarchy diagram. Performance based engineering, as stated in Vision 2000, does focus on levels on acceptable criteria for seismic risk depending on four levels on Earthquake recurrence intervals. Each design level has it's own goal for structural performance, fully operational, operational, life safe and near collapse level. As designing to fulfil so many performance objective might make the designing path, too long and confusing. The discussions in this paper will focus on how the designer can use system thinking concepts and software-supported methodology for managing the performance of seismic design by hierarchicall order with performance indicators to lower the complexity in the design process.

### PUSHOVER ANALYSIS OF MASONRY BUILDINGS: REMARKS ON CODE PROVISIONS – ID 555

*A. Giordano, University of Naples Federico II, Italy*
*M. Guadagnuolo, Second University of Naples, Italy*
*G. Faella, Second University of Naples, Italy*

Introduction It is well known that non linear dynamic analyses of 3D masonry buildings show difficulties both for the geometrical complexity and for the material behaviour, so that are often quite unfeasible for most practical applications. Recent research works have suggested that non-linear static analyses can be effectively used as a method to assess the structure capacity and to obtain an insight into its seismic behaviour. However, some issues arise from the applicability of pushover analyses to masonry buildings, especially as far as structural schemes and analysis methods are concerned. Moreover, non linear static procedures, as implemented in several seismic codes, i.e. mainly based on the concept of equivalent SDOF system, are affected by some uncertainties. This paper deals with the above mentioned subjects.

Methodology and results Some structural schemes are chosen according to different geometrical characteristics that can be considered representative of ordinary tuff masonry buildings. The non linear static analyses are carried out using two different modelling strategies: frame masonry and refined finite element approaches are used. The frame modeling of masonry buildings is based on results of recent research works developed by the authors. The finite element models, instead, feature a non linear constitutive theory widely used for materials whose behaviour is governed by cracking phenomena. The material parameters have been calibrated against laboratory tests by the authors in previous research works. As results, standard pushover procedure provides the seismic demand and the condition of the structure at demand point can be backwards determined. Such condition is compared with the one numerically computed by the finite element approach at the

same deformation/strength level. The comparison provides twofold information: the reliability of code procedure is investigated and the performance of frame masonry modelling strategy is verified.

### ROMANIAN CODE FOR ASSESSMENT OF EXISTING BUILDINGS. CONCEPTS AND METHODS – ID 578

*T. Postelnicu, Technical University of Civil Engineering, Romania*
*D. Zamfirescu, Technical University of Civil Engineering, Romania*

The paper presents the verifications and methods proposed for the next Romanian Code for the assessment of seismic performance of existent buildings. The Romanian Seismic Design Code P100/1992, was one of the first seismic design codes that included provisions regarding the assessment of the seismic performance of existent structures. However, the proposed method contained discrepancies and uncertainties as any other contemporary methods of that time. After the occurrence of the 1994-1995 earthquakes, consistent seismic evaluation codes were promptly developed in USA, New Zealand, Japan and Europe. The current EC8-3 devoted to the assessment and retrofit of buildings provides coherent assessment evaluation methodologies. However, some of the proposed principles and concepts can create confusions and difficulties for the practical application. An issue is the definition of the limit states and their associated events that is only partially correlated with the definition of the limit states for the design of new buildings. The proposed linear method implementing displacement-based verifications is very attractive from the theoretical point of view but some difficulties may arise for the practical application. The advantages offered by the elastic analysis for determination of the inelastic chord rotations, over a nonlinear static analysis, are debatable. The proposed Romanian Code for Assessment and Retrofitting of existing structures follows mainly the same methods as EN 1998-3 with some adjustments concerning the limit states, methods of analysis and RC elements capacities. More attention was given to the load path and correct structural layout rules. In order to check the EN 1998-3 equations for the assessment of the deformation and strength capacities of common RC structural elements, a set of tests for columns having reinforcement detailing usual to existent Romanian buildings was carried on. The feasibility of the EN 1998-3 and the Romanian Code methods were investigated for a simple frame structure.

### A CODE FOR CURTAIN WALL SYSTEMS IN SEISMIC REGIONS – ID 608

*I. Vlad, TUCEB, Romania*

Despite the fact that they are not part of the main structure, glass and aluminum curtain wall systems are far from being secondary in importance. The response of a curtain wall depends on the response of the structure to which it is connected; thus it depends not only on the characteristics of the ground motion that excites the base of the structure, but also on the dynamic characteristics of the structure itself. Up to 1990, buildings with curtain walls were practically absent in Romania. Today, glass and aluminum curtain walls are found in city centers and in many new buildings. The need for modern buildings led to the situation in which the private investors, together with certain autonomous administrations, finance buildings with claddings being carried out with different curtain wall systems. One single aspect has, unfortunately, been ignored by almost everybody: the peculiar characteristics of the seismic ground motion in Romania. The author of this paper was involved in the design of a high-rise building with a curtain wall system in a high seismic region, being confronted with an important problem: the lack of legislation for curtain wall systems. The paper presents only a summary of earthquake provisions of the Code that was elaborated for the Romanian "Ministry of Public Works", according to the requirements of the "Quality Law for Buildings" available in Romania. These provisions refer to: • the technical conditions for resistance and stability requirements; • the relation between the structural system of the building and its curtain wall system; • the inertia forces effect that act on the in-plan curtain wall system; • the seismic action effect as a result of the imposed deformations of the curtain wall.

Some conditions for the assembling of the curtain wall systems are also presented, in brief.

### MODIFICATION DISPLACEMENT FACTORS FOR NON LINEAR BEHAVIOR OF SOIL AND STRUCTURE. – ID 635

*J. C. Vielma Pérez, Universidad Centroccidental Lisandro Alvarado/UPC, Spain*
*W. Lobo Quintero, Universidad de Los Andes, Venezuela*
*P. Rivero Rivero, Universidad de Los Andes, Venezuela*

Recently, has become evident the convenience of applying to the performance based design, which requires to be able to calculate inelastic displacements with accuracy, in order to apply suitably the different damage thresholds from control, expressed generally by means of the inter-story drift. Main design codes coincides in recommend the indirect method to calculate the inelastic displacements, this method consists to calculate these from the maximum probable displacements obtained from elastic equivalent analysis, by the amplification with modification factors based only in the global ductility of the structure, without considering relevant characteristics relative to the degradation response of the structure nor to the considerations of the effect of nonlinear behavior of different kind of soils. In this work an alternative method is proposed to calculate of the inelastic displacements of buildings designed for three different ductility levels, made compatible with the procedure applied in elastic equivalent analysis applying to reduction response factors obtained by the consideration of nonlinear behavior of soil and structure. The displacement modification coefficients have been determined from stiff soils to soft soils, and expressions of C-$\mu$-T type are proposed for four types of structures: reinforced concrete frames, reinforced concrete frames with masonry infill, steel frames and reinforced concrete shear walls. Finally, a comparative study is presented, for the application of the displacement modification factors in determination of the inter-story drifts of buildings of low and intermediate height, against the prescribed usual process in Eurocode-8.

### SEISMIC DESIGN METHOD FOR SOFT FIRST STORY RC BUILDING – ID 638

*R. Kheir-Eddine, University of Science and Technology of Oran, Algeria*
*K. Koichi, Building Research Institute, Japan*
*T. Masaomi, Nagoya University, Japan*
*K. Hiroto, Building Research Institute, Japan*

Inspections of earthquake damage as well as the results of analytical studies have shown that structural systems with a soft first story "Piloti" can lead to serious problems during severe earthquake ground shaking.

The 1978 Miyagi-ken Earthquake caused brittle and severe damage to columns of the first floors of RC buildings, which had shear walls except in the first floors. This type of damage was more noticed in the 1995 Kobe Earthquake. Based on this fact, a design procedure which does not soft first story collapse was recommended in the Japanese Seismic Design Guidelines.

However, soft first story collapse might be admissible for Piloti buildings if the maximum response deformation angle of the first story can be kept to the level of the maximum response deformation angle supposed in beam sideway mechanism buildings. And since soft first story buildings have fewer and/or no shear walls to absorb the energy generated by an earthquake than those total collapse buildings, thus in order to hold the maximum response deformation angle of soft first story buildings to the same level as that of total collapse buildings, and according to the energy constant law, the horizontal load-carrying capacity required in the soft first story buildings must be increased in comparison with total collapse buildings.

In this paper, a procedure to determine the failure modes of a building with a soft first story from the failure modes of columns and walls at the soft story is demonstrated. This is used to develop a design procedure to secure the safety of those buildings allowing the soft first story collapse mechanism. For this the seismic capacity

and non-linear numerical analyses of typical RC buildings of 6-, 10- and 14 stories with soft first story are conducted to derive an expression based on the energy constant law.

### PERFORMANCE-BASED DESIGN OF REINFORCED CONCRETE FRAMES – ID 669

*M. A. Shayanfar, Iran University of Science and Technology, Iran (Islamic Republic Of)*
*M. Rahili Khorasani, Iran University of Science and Technology, Iran (Islamic Republic Of)*

Improper behavior of designed buildings by means of traditional codes in recent earthquake arouse the researchers to pursue a more certain method in building design. As a result of which, performance-based design method has been widely met welcomed and various accomplished researches have proved it to be sufficient in seismic response of structures. Thus, in the last two decades, the issue of energy has been much considered in earthquake resistant design of structures. Many parameters involved in design and evaluation of structures have become justifiable and applicable using this technique. However, numerous unknowns and defects are present in energy method which impedes it from being presented as a precise method in the form of a design code. According to current widespread researches which are being done on this issue all over the world, a bright future is predicted for it and it is likely that in a near future, the current principles and criteria in codes be replaced by principles and criteria of Energy. In this paper, a number of reinforced concrete frames have been designed and evaluated according to energy concept and performance level. The content of the paper is aimed to present a comprehensive method in seismic design of RC frames based on energy and performance level.

Key words: Performance-based design, RC frames, Energy concept, Dynamic nonlinear analysis

### MODAL COMBINATION OF THE MAXIMUM BASE SHEARS IN THE DIRECTION PERPENDICULAR TO THE EXCITATION – ID 690

*N. Ozhendekci, Yildiz Tech. Unv., Turkey*

By means of the combination rules of the modal maximum values of the dynamic response, modal superposition method has been widely used in the design of structures. For the combination of the maximum modal responses whose algebraic signs are not independent such as columns where a positive flexural moment is systematically associated to an axial compressive stress in a mode and to a tensile stress in another, AFRP recommends simply superposing them, instead of using the CQC rule. There is a similarity between the column example of AFRP recommendation and the calculation of the base-column shear forces whose direction is perpendicular to the earthquake-excitation direction for 3D torsionally coupled buildings. In this study, the recommendation of AFRP is adapted for the combination of these shear forces. The results of the AFRP recommendation and the CQC rule are compared with the results by time history analyses and the error values of these two rules are calculated. To this aim, a computer program coded and parametric analyses are performed for 315 one-storey buildings (3DOF) and 54 five-storey buildings under 12 historical earthquakes, 4428 analyses in total. It is found that, when CQC rule has high error values such as 500%, the rule proposed in the AFRP recommendation has the error values not much than 100% in absolute. However, when CQC rule has error values below than 100%, the rule of AFRP has error values near 100% again.

### EFFECT OF NEAR-FIELD GROUND MOTIONS ON THE INELASTIC FORCE AND DISPLACEMENT DEMAND OF BRIDGE STRUCTURE – ID 729

*G. Watanabe, Tokyo Institute of Technology, Japan*
*K. Kawashima, Tokyo Institute of Technology, Japan*

In the force-based seismic design of bridge structures, the force reduction factor has an important role in the determination of inelastic force demand of a bridge structure. Previous researchers conducted a comprehensive statistical study of constant ductility force reduction factor. However, in spite of the importance in seismic design, less attention has been paid to large dispersion of the force reduction factors depending on ground motions. On the other hand, the lateral displacement demand has not been taken into account in the force-based seismic design. Although the excessive nonlinear displacement response of a deck result in the failure of the superstructures due to the pounding between the adjacent decks and the failure of the restrainers, thus failure has not been taken into account. Since the maximum nonlinear displacement of a bridge deck and the residual displacement affect the retrofit and the serviceability after an extreme earthquake, to control the seismic damage of a structure, an adequate estimation of lateral displacement demand of the structure that exhibits non-linear behavior is also required. This paper discusses the lateral displacement demand of bridge structures based on the analysis of SDOF system. In the last decades, a number of near-field ground motions have been recorded. Since the near-field ground motion resulted in the severe damage to the bridge structures, the interest of the mechanism of generation and the effect on the seismic response has peen paid. From the previous researches, the importance of the directivity of near-field ground motions and longer period impulsive ground motions are considered. A special emphasis of this paper is the effect of near-field ground motions on the inelastic force and displacement demands of bridge structures.

### REPARABILITY DEMAND SPECTRUM OF R/C BUILDINGS DUE TO THE LIFECYCLE SEISMIC LOSS ESTIMATION – ID 807

*N. Takahashi, The University of Tokyo, Japan*
*Y. Nakano, The University of Tokyo, Japan*
*H. Shiohara, The University of Tokyo, Japan*

The performance-based seismic design procedure has aimed to define and estimate the multiple type of building performance using quantified parameters. Especially the performance of reparability relates strongly to the quantified parameter such as repairing costs, and the well-established method for assessing and estimating the quantified parameter is needed at first. Though this approach is very important for the improvement of performance-based seismic design procedure, it may be inefficient unless the engineer using the procedure is capable of developing preliminary designs that have the desired performance. The performance-based seismic design in the next generation therefore should address the development of design guidance that assists the engineer to design the desired performance including a reparability. In this research, the idea of the reparability demand spectrum for R/C buildings is proposed. The reparability demand spectrum is visualized from the expected running cost to repair a building structure damaged by earthquakes through its lifetime, where the equivalent seismic loss is converted to the relation of spectral base shear coefficients and spectral yield displacements by means of the single-degree of freedom nonlinear time history analysis. Finally the availability of the proposed method is further investigated its practical use for the preliminary seismic design in the future.

### APPLICATION OF ENDURANCE TIME METHOD FOR ESTIMATING MAXIMUM DEFORMATION DEMANDS OF STRUCTURES – ID 872

*H. Tajmir Riahi, Sharif University of Technology, Iran (Islamic Republic Of)*
*H. E. Estekanchi, Sharif University of Technology, Iran (Islamic Republic Of)*
*A. Vafai, Sharif University of Technology, Iran (Islamic Republic Of)*

Performance-based seismic design methodologies aim at controlling earthquake damage to structural elements and many types of nonstructural elements by limiting lateral deformations on structures. Limiting lateral deformations requires an adequate estimation of peak lateral deformation demands on structures, particularly when subjected to severe ground motions in which

the structure is likely to undergo inelastic deformations. The concept of the Endurance Time (ET) method is used for such estimation. Gradually intensifying accelerograms are created in a manner that the linear and nonlinear response spectra of them, while being proportional to average of real earthquakes spectra, intensifies in a uniform manner with time. For reaching this goal a relatively large number of earthquake ground motions are used to calculate the linear and nonlinear spectra. These earthquakes organized into different ensembles of ground motions, representing large or small earthquake magnitude and distance, and different site classes. Near-fault ground motions are also included. The nonlinear spectra are presented for bilinear non-degrading systems over the complete range of elastic vibration period. By increasing the time of intensifying accelerograms their response spectra change from small earthquake magnitude spectra to large earthquake magnitude spectra. The results of ET analysis are compared with approximate methods that have been proposed in the past to estimate the maximum inelastic deformation demand on existing structures. These approximate methods include both equivalent linearization and displacement modification factor methods. Also the results of ET analysis are compared with "exact" results from nonlinear response history analysis. Errors and standard errors, as well as probability of underestimating or overestimating inelastic deformations, are presented and discussed. Finally application of the method in some simple MDOF structures is examined. Results are compared with other conventional methods like static pushover and incremental dynamic analysis.

Keywords: Dynamic pushover analysis, Seismic design criteria, Endurance Time Method, Approximation methods, Deformation.

## CALCULATION OF FOLDING ANGLE OF RAILWAY VIADUCT ON THE SOFT GROUND WITH NON-FLAT BASE – ID 906

*T. Kawanishi, Railway Technical Research Institute, Japan*
*Y. Murono, Railway Technical Research Institute, Japan*
*H. Aoki, JRTT, Japan*
*T. Yamazaki, JRTT, Japan*

In Japanese seismic design of railway structures, a folding angle of railway viaduct must be checked in order to secure the running stability of trains. On the soft ground with non-flat base, surface waves would be generated at basin edge and propagate in the horizontal direction. These wave propagating characteristics are called 'basin effects'. The folding angles, therefore, are strongly influenced by the basin effects. A conventional method, however, hasn't been developed for calculating folding angles taking into account those influences. The purpose of this paper is to clarify how the basin effects control the folding angles of railway viaducts and to develop a method for calculating the angles considering the influences. At first, characteristics of seismic ground behavior in the out-of-plane direction are clarified by using dynamic FEM analyses. After that, seismic deformations of viaducts constructed on the soft ground with non-flat base are calculated. The folding angles are determined by using these seismic deformations, and we investigate how the folding angles are influenced by the parameters, which is the inclination of a bedrock, the thickness of a surface ground, and the impedance ratio between a surface ground and a bedrock. Finally, a simple method is formulated for calculating folding angles which can take into account the basin effects. The efficiency of our proposed method is confirmed by comparing with results from dynamic FEM analyses.

## SEISMIC DESIGN OF SPACE STEEL FRAMES USING ADVANCED METHODS OF ANALYSIS – ID 915

*D. Beskos, University, Greece*
*A. Vasilopoulos, Greece, Greece*

A rational and efficient seismic design methodology for space steel frames using advanced methods of analysis in the framework of Eurocodes 8 and 3 is presented. This design methodology employs an advanced finite element method of analysis that takes into account geometrical and material non-linearities and member and frame imperfections. Seismic loads and resistances (strengths) are computed according to Eurocodes 8 and 3, respectively. The inelastic dynamic method in the time domain is employed with accelerograms taken from real earthquakes scaled so as to be compatible with the elastic design spectrum of Eurocode 8. The design procedure starts with assumed member sections, continues with the ultimate load carrying capacity check, the serviceability check, the damage and the ductility check and ends with the adjustment of member sizes. Thus it can sufficiently capture the limit states of displacements, strength, stability and damage of the structure and its individual members so that separate member capacity checks through the interaction equations of Eurocode 3 or the usage of the conservative and crude q-factor suggested in Eurocode 8 are not required. Two numerical examples dealing with the design of (a) a space three storey steel frame with one bay in both horizodal directions and (b) a space seven storey steel frame with two and three bays along its two horizodal directions are presented to illustrate the method and demonstrate its advantages.

Keywords: Seismic design; Space steel frames; Finite element method; Advanced analysis methods; Inelastic dynamic analysis; Eurocode 8; Eurocode 3

## COMPARISON OF PROBABILISTIC AND DETERMINISTIC ASSESSMENTS FOR EVALUATION OF SEISMIC SAFETY OF NUCLEAR POWER PLANTS IN SLOVAKIA – ID 925

*J. Kralik, Slovak University of Technology, Slovakia (Slovak Republic)*

This paper gives the experiences from the seismic analysis of the operated nuclear power plants (NPP) in Slovakia. The earthquake resistance analysis of NPP buildings in Slovakia were based on the recommends of international organization IAEA in Vienna to get international safety level of nuclear power plants. Two possibilities for seismic design of operating nuclear facilities, for instance, NPP structures and technologies, we have – Seismic probabilistic risk assesment (SPRA) and Seismic margin assessment (SMA). The SPRA methodology as an integrated process that includes consideration of the uncertainty and randommes of the seismic hazard, structural response, and material capacity parameters to give a probabilistic assessment of risk. The SMA methodology was designed to demonstrate margin over the design earthquake level to guantify plant safety. In contrast, the SPRA provides estimates of seismic risks of core damage and adverse public health effects. The seismic load for the NPP site was defined by peak ground acceleration (PGA) and local seismic spectrum in dependence on magnitude and distance from source zone of earthquake. The seismic response can be calculated in the frequency (spectrum response analysis) or time domain (transient analysis). The earthquake input is specified in terms of free-field ground motion accelerograms for time-history dynamic analyses. The foundation of the reactor building is embedded into the subsoil. This embedment has generally two effects on the dynamic analysis of the building: To provide input excitations to structural models for sites with no strong ground motion data, it is necessary to generate artificial accelerogram. Thus, the simulated earthquake records must have realistic duration, frequency content, and intensity, representing the physical conditions of the site. In consideration of the works presented by more authors, the recommendations regarding the earthquake analysis of buildings including site effects will be described in paper.

## SEISMIC DESIGN OF FLAT-BOTTOM SILOS CONTAINING GRAIN-LIKE MATERIAL – ID 982

*F. Aptikaev, Institute of Physics of the Earth, RAS, Russian Federation*
*G. Gasparini, DISTART - Department of Civil Engineering, Italy*
*T. Trombetti, DISTART - Department of Civil Engineering, Italy*
*S. Silvestri, DISTART - Department of Civil Engineering, Italy*

This paper proposes an innovative methodology for the seismic design of flat-bottom silos containing granular, grain-like material. In the general issues concerning the actions provoked

by earthquake ground motion on the walls of flat-bottom grain silos, the assessment of the horizontal actions seems to be of particular interest. Up to date, the horizontal actions due to the seismic event are usually evaluated under the hypotheses (i) of stiff behaviour of the silo and its contents and (ii) that the grain mass corresponding to the whole content of the silo except the base cone with an inclination equal to the internal friction angle of the grain is balanced by the horizontal actions provided by the walls (supposing that the seismic force coming from the base cone is balanced by friction and therefore does not push against the walls). This paper presents analytical developments devoted to the evaluation of the effective behaviour of flat-bottom silos containing grain, as subjected to earthquake input. The analyses reported here, which are developed by simulating the earthquake ground motion with constant vertical and horizontal accelerations (time-history dynamic analyses are not carried out), lead to the subdivision of the ensiled material into three different portions depending on the interaction with the container, by means of plain dynamic equilibrium considerations with reference to the above mentioned accelerations (that take into consideration the specific mutual actions developing in the ensiled grain). Two portions push (in different ways) into the silo walls, while the third one does not push into the silo walls. The findings indicate that, in the case of silos characterised by specific (but usual) height/diameter slenderness ratios, the portion of grain mass that interacts with the silo walls turns out to be noticeably lower than the total mass of the grain in the silo.

## DESIGN PROCEDURES FOR ECCENTRICALLY BRACED FRAMES – ID 1053

*H. Köber, Technical Univ. of Civil Engineering Bucharest, Romania*

Well-designed seismic resistant eccentrically braced frames are configured so that during strong earthquakes plastic deformations are concentrated mainly in the dissipative members, called links. To provide this, the links are sized for code specific lateral loads and all the other structural elements (columns, braces and beam segments outside the dissipative members) are designed for an increased value of the lateral loads. Six eccentrically braced frames were sized according to the design procedures contained in four different norms: - Seismic Provisions for Structural Steel Buildings - AISC; May, 2002 - Eurocode 8, Design of Structures for Earthquake Resistance – Revised Final Draft; May, 2002 - Calculul elementelor structurale din oţel - Design of Structural Steel Members – Bucharest, 2003 - Calcul des structurues pour leur résistance aux séismes, Norme Européene EUROCODE 8 – Décembre, 2003; (the same procedures are contained in Code for Aseismic Design of Residential Buildings, Agrozootechnical and Industrial Structures (P100-92) – Bucharest, 2004). Dynamic nonlinear analyses were performed with each of the designed structures.

## EFFECTS OF SSI IN THE CAPACITY SPECTRUM METHOD – ID 1073

*E. Saez, Ecole Centrale Paris, France*
*F. Lopez-Caballero, Ecole Centrale Paris, France*
*A. Modaressi, Ecole Centrale Paris, France*

In the present earthquake engineering practice, the capacity spectrum method is a widely used strategy for seismic performance evaluation of existing and new structures. This non-linear static approach is based on well known approximations (e.g. constant lateral simplified force distribution, fundamental elastic modes, etc.). Several authors have reported deficiencies of the general procedure: inaccurate deformation predictions and no convergence of iterative procedures given in design codes among others.

Furthermore those deficiencies, some aspects such as the effect of the ratio of fundamental frequency of input signal and this one of the structure and the alteration of the seismic response of a structure due to the flexibility of its soil foundation (i.e. soil-foundation interaction effect) are usually ignored.

The purpose of this work is to improve the non-linear static analysis procedure in order to take into account both SSI effects and the input signal characteristics. Numerical simulations of pushover test and non-linear dynamic analyses of a non-linear conceptual frame structure are performed in order to study the role of several parameters on the structure response. This parametric study concerns the mechanical properties of the soil foundation (e.g. VS30 and fundamental frequency) as well as the characteristics of the input motion (e.g. amplitude, frequency content and equivalent number of cycles). Thus a 2D finite element modelling is carried out using an elastic-plastic model to represent the structure behaviour and a non-linear elastoplastic model to represent the soil behaviour.

The obtained responses are compared with the procedures included in some design codes to account the soil-structure interaction effect.

## DAMAGE CONTROLLED SEISMIC DESIGN OF STEEL FRAMED STRUCTURES – ID 1126

*G. Hatzigeorgiou, Democritus University of Thrace, Greece*
*D. Beskos, University of Patras, Greece*

A new seismic design philosophy based on the concept of damage is presented and applied to steel framed structures. The proposed direct damage controlled seismic design method quantifies and controls damage in a direct and transparent manner much better than any other of the existing methods. The method appropriately combines realistic nonlinear stress-strain relations for steel with a simple expression for damage to design steel members or whole steel framed structures under seismic loading with the aid of the fiber beam model and the finite element method. Both material and geometric nonlinearities are taken into account in the formulation. Using this method, the engineer can either determine the damage level for a given structure and known loading, or dimension a structure for a target damage level and known loading, or finally determine the maximum loading for a given structure and a target damage level. The method is illustrated by means of two examples, where the first one deals with the design of a three-dimensional truss structure, while the second one with the design of a two-dimensional steel frame, both under seismic loading. Comparisons with the results of seismic design based on current codes are also made.

## DRIFT CONTROL IN THE SEISMIC DESIGN CODES – ID 1160

*L. Andrade Insúa, ROSE School, Italy*
*A. Muñoz Peláez, Pontificia Universidad Católica del Perú, Peru*

Earthquakes around the world have shown the close relationship between lateral displacements and structural and non-structural damage in buildings. This has motivated that both the calculation procedures and the maximum drift allowable had to be revised in the seismic design codes of many countries.

For that reason, the objective of this work is the study of the stiffness demands required in some of the most important seismic design codes of the world, from the point of view of the drift control.

This paper presents a methodology for evaluating how strict are the codes in controlling the drift and a comparative study is carried out between the current codes of Peru, Chile, Colombia, Mexico, Turkey, USA (UBC and IBC)and EUROCODE 8.

It is shown that the maximum drift allowable for the protection of a group of buildings of similar characteristics are function of the dispersion of the construction quality and that it is reasonable that in countries with great dispersion in the quality of construction procedures, small limits have to be adopted to achieve a satisfactory protection.

It is concluded that the procedures and limits for the calculation and control of the drift are mainly based on the experience of professionals of each country than in analytic and experimental research.

The results of this study showed that for short periods, up to 0.45 sec., the Peruvian code is the most rigorous in the drift control, for periods between 0.45 to 1.20 sec. the Colombian code is the most rigorous, the EUROCODE 8 is the most rigorous for periods from 1.20 sec to 1.60 sec, and the Chilean code together with the EUROCODE 8 are the most rigorous for periods above 1.60 sec.

On the other hand, among the less strict codes in the drift control are the American IBC and UBC.

### PROPORTIONING REINFORCED CONCRETE BUILDINGS FOR DISPLACEMENT-BASED DESIGN – ID 1222

*L. B. Fargier Gabaldon, Universidad de los Andes, Venezuela*

A simple procedure for proportioning regular low-rise reinforced concrete buildings to limit the drift ratio is presented in this paper. The procedure allows the designer to provide the building with a target period that will limit the maximum drift demand expected during an earthquake event and is based on a plastic design methodology. The implementation of the procedure is simple, only a Design Spectrum and a hand calculator are needed. An example that includes proportioning a five story building for a 2.5% maximum story drift is fully worked. To validate the proposed procedure a nonlinear time history analysis was conducted on the proportioned building. Results obtained from such analysis yielded maximum story drifts in the order of 2.0%. Based on these results the proposed procedure seems to be an effective tool to proportion regular low-rise reinforced concrete buildings for Displacement Based-Design.

### ACCELERATION DEMANDS FOR NONSTRUCTURAL COMPONENTS EXPOSED TO NEAR-FAULT GROUND MOTIONS – ID 1248

*R. Sankaranarayanan, University of Maryland, United States*
*R. Medina, University of Maryland, United States*

This study consists of the statistical evaluation of floor response spectra for elastic Non Structural Components (NSCs) exposed to pulse-type, near-fault ground motions. The focus is on NSCs that can be modeled as single-degree-of-freedom systems mounted on regular moment-resisting buildings undergoing different levels of inelastic deformation. Moment-resisting frames with periods from 0. 6 s. to 3.6 s. and total heights from 11 m to 66 m are utilized. The NSCs under consideration have small masses as compared to the total mass of the supporting structure; thus, dynamic interaction effects are ignored. The structural response caused by near-fault ground motions may be significantly influenced by the presence of a velocity pulse in the fault-normal component. Hence, the ground motions used in this study correspond to fault-normal components that have been classified into different groups based on the relationship between their pulse duration and the modal periods of the supporting structure.

Results indicate that current seismic code provisions may underestimate the effects of the higher modes of the supporting structure on the peak acceleration demands experienced by NSCs. In general, for frames with distributed inelasticity and exposed to nonnear-fault ground motions, there is a reduction in the acceleration response of NSCs caused by inelastic action of the supporting structure. This study demonstrates that this reduction is not as pronounced for systems subjected to near-fault ground motions. Recommendations are provided to estimate floor response spectra for the design of NSCs mounted on inelastic frame structures that are exposed to pulse-type, near-fault ground motions.

### ELASTIC DISPLACEMENT RESPONSE SPECTRA – ID 1252

*D. Manou, Aristotle University of Thessaloniki, Greece*
*D. Raptakis, Aristotle University of Thessaloniki, Greece*
*K. Pitilakis, Aristotle University of Thessaloniki, Greece*

In this paper, certain issues concerning the difficulties on the estimation of reliable displacement response spectra are discussed, in view of performance based design. In particular, emphasis is given on the cutoff of the spectral values corresponding to high frequency values, on the reliable estimation of the design ground displacement dg necessary for the computation of the normalized response spectra, and finally on the time histories processing using different types of filters. Experimental data and theoretical analyses were used. A large number of carefully selected seismic records on well documented soil conditions (in terms of Vs profile, mechanical and dynamic soil properties, depth of the basement rock) are used, which were mainly provided from the Japanese strong motion network Kik-net and the Greek accelerometric network. Regarding the theoretical 1D ground response analyses, the selection of the soil profiles was based (a) on the consideration of the basic parameters that affect the characteristics of the seismic response applying an "equivalent linear" approach to model the seismic behavior of the ground and (b) the actual stratigraphy and ground properties in real conditions that are basically found in Greece. The discussion mainly focuses on the elastic displacement spectra of soil classes B and C (Eurocode 8) and partly on other soil classes of the Greek Seismic Code (EAK2000) and of EC8, including the revised provision of EC8-Draft 4, May 2002 as well as the proposed new soil classification and related elastic spectra (Pitilakis, Gazepis & Anastasiadis, 13th WCEE, Vancouver 2004). The aim of this paper is (a) to highlight the need for systematic research on design displacement spectra, given the fact that the suggested spectra in almost all the current Seismic Codes differ considerably from actual seismic records and (b) to propose in a preliminary step more reliable elastic displacement spectra.

### EVALUATION OF THE CODE-SPECIFIED DISTRIBUTION FOR BASE SHEAR IN BASE-ISOLATED BUILDINGS – ID 1269

*B. Mehrparvar, Tehran Polytechnic, Iran (Islamic Republic Of)*
*F. Khoshnoudian, Tehran Polytechnic, Iran (Islamic Republic Of)*

Current seismic codes assume a triangular distribution of base shear for isolated buildings similar to their fixed-base counterparts. In this paper the validity of such distribution is investigated for isolated structures having elastomeric isolators. So different models of isolation systems are selected that cover a wide range of elastomeric isolators with low to high stiffness and damping. The results of non-linear time-history analysis on these models show some conservatism in code-specified distribution compared with the observed distribution of story forces. Also a new formula is proposed instead of the triangular distribution to make a better estimation of real behaviour of seismic isolated buildings.

### SEISMIC DESIGN OF BEAM-COLUMN JOINTS IN RC MOMENT RESISTING FRAMES – ID 1328

*A. Mortezaei, Islamic Azad University, Iran (Islamic Republic Of)*
*A. Kheyroddin, Semnan University, Iran (Islamic Republic Of)*

The behavior of the reinforced concrete moment resisting frame structures in resent earthquakes all over the world has highlighted the consequences of poor performance of beam-column joints. Large amount of research carried out to understand the complex mechanisms and safe behavior of beam-column joints has gone into code recommendations. This paper presents critical review of recommendations of well-established codes regarding design and detailing aspects of beam-column joints. The codes of practice considered are ACI 318M-02, NZS 3101 and Eurocode 8 of EN 1998-1: 2003. All three codes aim to satisfy the bond and shear requirements within the joint. It is observed that ACI 318M-02 requires smaller column depth as compared to the other two codes based on the anchorage conditions. NZS 3101 and EN 1998-1: 2003 consider the shear stress level to obtain the required stirrup reinforcement whereas ACI 318M-02 provides stirrup reinforcement to obtain the axial load capacity of column by confinement. Significant factors influencing the design of beam-column joints are identified and the effect of their variations on design parameters is compared. The variation in the requirements of the shear reinforcement is substantial among the three codes.

Key words: beam-column joint, moment resisting frame, anchorage, stirrup reinforcement.

Contacts: mortezaei@semnaniau.ac.ir , akheirodin@semnan.ac.ir

### SEISMIC DESIGN OF R.C. SHEAR WALLS STRUCTURES: DISCUSSION ON CODE PROVISIONS AND DUCTILITY DEMANDS – ID 1448

*A. Giordano, University of Naples, Italy*
*S. Nardella, Italy*
*G. Faella, University of Aversa, Italy*

Introduction Following the orientations of the modern design principles widely accepted in the research community, national codes have implemented requirements aimed at assuring that seismic-resistant structures can keep a fixed strength level, though undergoing severe inelastic deformations in case of earthquake occurrence. Ductility is regarded as the main aspect of the structural behaviour, and, inheriting the well known criteria of capacity design, strict provisions in terms of structural details are provided. However, a few issues arise in case of r.c. structural systems featuring shear walls and flat beams. Actually, high ductility demands are not expected elsewhere than at walls bases. In the opinion of the authors, this may render some code requirements, for example in terms of transverse reinforcement at beam ends excessively severe, besides difficult for the executors. This paper deals with the above mentioned aspects.

Methodology and results As test examples, some structural schemes are chosen featuring r.c. shear walls and flat beams, which is recurrent in ordinary buildings. The reinforcement is calculated and detailed according to the newly introduced Italian seismic code. In order to determine the ductility demands, pushover analysis is carried out using different modelling strategies for the inelastic behaviour. Concentrated plasticity (plastic hinges) and diffused plasticity (fibres) models are used. The models are accurately calibrated using either the provisions of the code itself or research suggestions commonly regarded as reliable. As results, the ductility demands at section level are determined and compared. Also Eurocode provisions are implemented for additional analysis.

Conclusions The analysis carried out in this paper show that for r.c. buildings with shear walls and flat beams, the ductility demands at beam section level are always very low. For this reason, present code provisions aimed at providing the beams with high ductility do not seem to be justifiable.

### APPLICATION OF FEMA 356 TO THE SEISMIC ASSESSMENT OF EXISTING NUCLEAR FACILITIES IN THE UK – ID 1515

*S. Gallocher, Halcrow Group Ltd, UK*
*C. Robertson, Halcrow Group Ltd., UK*
*A. Manafpour, Halcrow Group Ltd., UK*
*D. Kourepinis, Halcrow Group Ltd., UK*

Seismic qualification of existing nuclear facilities is often problematic. For example in the UK once such structures were designed to satisfy (non-seismic) codes of practice, current at the time of construction, and they are obviously unable to comply retrospectively with the prescriptive capacity design procedures incorporated in modern seismic standards. Although satisfying an essentially elastic design basis may be achievable at a certain seismic level, demonstration of an adequate margin beyond this needs a more fundamental approach based on the principles of mechanics and a full understanding of the structural behaviour linked to detailing. Performance based methods are an attractive solution to these types of problems since they are non-prescriptive in terms of the design strength and detailing, allowing the system response to be significantly enhanced by strengthening at a component level based on analysis results taken directly from the mathematical model. This represents a significant advance on conventional methods that can lead to the unrealistic or inadequate assessment of buildings without the identification of the true failure modes. This paper performs a critique of some of the current approaches applied in the nuclear industry and considers the implications of adopting a methodology based upon FEMA 356.

### A REVIEW OF MODIFICATIONS IN THIRD EDITION OF IRANIAN CODE OF PRACTICE FOR SEISMIC RESISTANT DESIGN – ID 1541

*M. Tehranizadeh, Amirkabir University, Iran (Islamic Republic Of)*
*A. Khajeh Samani, Amirkabir University, Iran (Islamic Republic Of)*

Passing years after publication of the second edition of Iranian Code of Practice For Seismic Resistant Design of Buildings, the urge for its revision has been felt. In this paper, some modifications of the third edition of the code such as scope, geotechnical provisions, architectural provisions, occupancy category, vertical component and acceleration amplification is reviewed, Some of which consist of editorial rectifications and some others hold conceptual modifications. A comparison among the third edition of the code, the second edition of standard number 2800, Eurocode-8 acceleration amplifications and UBC-97's spectral acceleration is made.

### PERFORMANCE BASED DESIGN – ID 1545

*A. Nazarirad, AmirKabir, Iran (Islamic Republic Of)*
*M. Tehranizadeh, AmirKabir, Iran (Islamic Republic Of)*

Performance based design is a subject in earthquake engineering which has been given more attention in last few years . Recent codes of practice which are based on force are suitable for elastic limit design , but performance levels which are acceptable in damage can be described with displacement criteria. Therefore displacement may be best criteria for defining damage index and performance base design. In this study beside discussing about principle of performance base design the acceptance criteria, displacement criteria, capacity spectrum method and all parameters which are affected on displacement are investigated. Performance level of studies structures are determined and the results are compared with the purpose of Iranian code of practice (2800). Above proposals for three steel structure buildings; high, medium and short with base method "Nonlinear dynamic analysis" are controlled and the results are compared. In conclusion; the effect of gravity and lateral loads by nonlinear static and dynamic analysis methods have been studied. Comparison of displacement from these two methods according to acceptance criteria, and also acceptability of structure performances which are designed according to Iranian code of practice (2800) are presented and some recommendations for further studies have been given.

### COMPARISON OF DESIGN SPECIFICATIONS FOR SEISMICALLY ISOLATED BUILDINGS – ID 1571

*U. Akyuz, Middle East Technical University, Turkey*
*E. Acar, Ari Project, Turkey*

Seismic isolation consists of the installation of mechanisms, which decouple the structure, and its contents, from potentially damaging earthquake induced ground motions. The isolator increases the natural period of the overall structure and hence decreases its acceleration response to earthquake-generated vibrations. This increase in period, together with damping, can markedly reduce the effect of the earthquake, so that less damaging loads and deformations are imposed on the structure and its components. The aim of this study is to investigate the effects of seismic base isolation systems, especially rubber bearings, on the response of structures. The study includes analysis of the seismic responses of isolated structures, which is oriented to give a clear understanding of the effect of base isolation on the nature of the structure. The notes introduce the related chapters of FEMA 273 and IBC2000 regulations for the seismic isolated structures. These provisions and formulas, their similarities and differences, are presented. Four different types of buildings are used in the analyses. Three of them are symmetric buildings with three, five and eight stories, and one is an unsymmetric building with five stories. All structures are assumed to be serving as school buildings. The isolated buildings are analyzed by using Static Equivalent Lateral Force, Response Spectrum and Time History methods. A commercial computer package, namely SAP2000, is used for 3D analysis of the structures. The analyses of these isolated buildings are done for various soil types. The basic motive is to identify the similarities and differences between the design code IBC2000, and

design specification FEMA 273, and make a comparison between them from the design of base isolated structures point of view.

### RECOMMENDATION FOR RESPONSE MODIFICATION FACTOR (R) OF ELEVATED CONCRETE TANKS – ID 1899

*M. Masoudi, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iran (Islamic Republic Of)*
*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*

This paper discusses the failure mechanism of elevated concrete tanks with shaft and frame staging (supporting system) along with seismic behavior of such structures. In order to modify the current code-based seismic design methodology, computer models have been established to determine the Response Modification Factors (R) of the shaft and frame staging elevated tanks. By performing linear and nonlinear time history analyses on these models for 9 different earthquakes; the effects of multi component earthquakes, fluid-structure interaction and P-Delta; on the inelastic behavior of them have been determined. Based on these results, (R) factors for shaft and frame staging elevated concrete tanks with regards to the seismicity of the site, have been recommended.

## ES 6: Lifeline Systems

Level-1

### SEISMIC HAZARD ASSESSMENT OF SOUTH WESTERN OF IRAN – ID 184

*G. Ghodrati Amiri, Iran University of Science & Technology, Iran (Islamic Republic Of)*
*A. Kaveh, Iran University of Science & Technology, Iran (Islamic Republic Of)*
*S. A. Razavian Amrei, Iran University of Science & Technology, Iran (Islamic Republic Of)*

This paper presents a probabilistic seismic hazard assessment of a region in south western of Iran, including Bushehr, Borazjan, Genaveh port, and Righ port. Two maps have been prepared to indicate the earthquake hazard of this region and its vicinity in the form of iso-acceleration contour lines. They display the probabilistic estimate of Peak Ground Acceleration (PGA) over bedrock for the return periods of 475 and 950 years. South western part of Iran plays an important role in economy of Iran and the region under study contains three oil fields, oil pipe lines, important fishing and commercial ports and nuclear power station. Many destructive earthquakes happened in Iran in the last centuries. The oldest one happened in the 10h century AD. A collected catalogue, containing both historical and instrumental events and covering the period from the 10th century AD to 2002 is then used. Seismic sources are modeled and recurrence relationship is established. For this purpose the method proposed by Kijko [2000] was employed considering uncertainty in magnitude and incomplete earthquake catalogue. The calculations were performed using the logic tree method and three weighted attenuation relationships; Ramazi [1999], 0.4, Ambraseys &Bommer [1991], 0.35, and Sarma & Srbulov [1996], 0.25. Seismic hazard assessment is then carried out for 17*12 grid points using SEISRISK III. Finally, two seismic hazard maps of the studied area based on Peak Ground Acceleration (PGA) over bedrock for 10% probability of exceedence in two life cycles of 50 and 100 years are presented. The results showed that the PGA ranges from 0.08(g) to 0.38(g) for a return period of 475 years and from 0.10(g) to 0.44(g) for a return period of 950 years. Since oil industries and commercial port play a significant role in economy of Iran, risk of future earthquakes will be very significant.

### ADVANTAGES AND CONSIDERATIONS IN APPLICATION OF BASE-ISOLATION TO SUBSTATION TRANSFORMERS – ID 214

*M. A. Saadeghvaziri, NJIT, United States*

This paper presents seismic performance of electric substation transformers, and discusses advantages and considerations in the use of base-isolation as a viable hazard mitigation option. Substation transformers and bushings are the most critical elements within the power delivery system and their performances during past earthquakes in the US and abroad have not been satisfactory. Finite element analyses indicate that interaction between these two critical elements has a significant effect on seismic vulnerability of substations. In light of dynamic characteristics of these equipment, base-isolation can be very effectively in mitigating this adverse interaction. Furthermore, due to high-inertia reduction, base-isolation can also have beneficial effects on long-term longevity of transformers and on foundation performance during seismic events. Larger displacement demand and uplift, however, are issues that must be considered in application of base-isolation. Through an actual case study (433.3 MVA transformer in a high-voltage substation) design concepts will be investigated that will demonstrate larger displacement can be accommodated; and that considering transformer geometry, peak ground acceleration, amount of inertia reduction and isolator's friction coefficient for this transformer uplift is not an issue.

### DISASTER MANAGEMENT IN ELECTRICAL NETWORK AND POWER LIFE LINE – ID 229

*K. Fallahi, MAPNA Co., Iran (Islamic Republic Of)*

Extensive research works toward the perception of natural events and phenomena, has been resulted in the recognition of these destructive natural forces. Natural events such as Flood, Earthquake and their disastrous consequences have established a new scientific field as called "Disaster Management Science". Nowadays the future horizons are further and more promising in the comparison with the past, and possibly for this reason human enthusiasm for challenging the unknown forces have increased significantly. In spite of improving the science & techniques in the different fields, human science can not detect the exact time of occurring such events .Therefore, it is necessary to be equipped against the unforeseen events. Occurrence of disastrous events and crisis has a special stand in electrical energy production industry. Iran due to its location is severely exposed to the natural phenomena such as floods, storms, earthquakes etc.., so for this reason, keeping and maintaining the stable flow of vital energy in any form such as the electricity is a prominent concern. Increasing demand for energy especially in the field of electricity at different periods and in particular case of disaster with respect to the huge amount of capital investment requires special attention and management at the time of disaster and crisis. This research is concentrated on the study about principles of the "Disaster Management", in according to the conditions prevailing for production of electrical energy, transmission networks and their related organization. It also suggests a special board and arrangement for establishment the disaster management.

### EXISTING POWER GENERATION AND NETWORK FACILITIES IMPROVEMENT AGAINST SEISMIC DAMAGE – ID 234

*K. Fallahi, MAPNA Co., Iran (Islamic Republic Of)*

Utilization of hydraulic potential energy and thermal energy by construction of power plants which are generally situated at some remote locations and are far from consumption ports, necessiate the establishment of transmission system (lines) and substations. Due to vastness of regions and existence of different conditions attributed to the ground, the outbreak of various incidents, such as earthquake is probable. Although the damages , inflicted upon power utility system are not significant, but interruption in production of electrical energy and transmission of this energy at any moment and profound investments , requires a special attention to observe the behavior and responses of current seismic forces. The experience of past earthquakes shows

that, although damages of the Electrical network installation are very extensive in length and area, they are infrequent. But the significance of these installations makes their protection and stability more important. Concerning the importance of utilization of energy, improving the current situation, increasing the safety level for availability of electrical equipment and future projects, it is necessary to take some procedures into consideration to prevent or lessen the destructive consequences of earthquakes. According to the investigation about past earthquakes and the transmission lines condition in our country, some of them will probably have considerable damages. Since earthquake is unpreventable, the necessity of reliable, fast and simple method to retrofit of the existing installations is obvious. Therefore, Finding practical retrofitting methods for vulnerable installations and preventing them from further damages by improving design methods is of special significance.

This research work concentrate on the study about "seismic retrofit planning methods, seismic upgrading design for power network facilities based on the foreseen seismic risk assessment of electrical power generation and distribution systems.

## EXPERIMENTAL STUDY ON SOIL-PIPELINE INTERACTION DUE TO LARGE GROUND DEFORMATION – ID 381

*E. Faccioli, Dept. Structural Eng., Politecnico di Milano, Italy*
*S. Takashi, Tokyo Gas Co., ltd, Japan*

Earthquake-induced Permanent Ground Deformation (PGD) can significantly affect underground lifelines, such as buried gas and water pipelines. To assess the integrity of the pipelines against such ground movements, it is important to quantitatively evaluate the interaction between the pipelines and the surrounding soil. The soil-pipeline interaction specified in the major seismic design guidelines for pipelines has a bilinear force-displacement relationship curve. The actual experimental results conducted by Trautmann and O'Rourke, however, showed that the force gradually decreased when the relative displacement between soil and pipe is 0.1m in the case of dense sand for backfill. Therefore, it is expected that the soil-pipe interaction is much smaller in the case of large ground deformation. In this study, full-scale experiments were conducted to evaluate the soil-pipeline interaction in the case of large ground deformation. The 100-mm-diameter pipe was installed and backfilled in a test compartment which had inside dimensions of 3.5m by 2.0m by 1.4m depth. The test pipe was installed at a 0.6m depth from the ground surface. The soil-pipeline interaction was measured up to 400mm relative displacement between soil and test pipe. Furthermore, finite element analyses were conducted to investigate the deformation behavior of buried pipelines, 400-mm-diameter pipeline with a 90-degree, against large ground deformation using the obtained experimental data.

## DEVELOPMENT OF NATIONAL IRANIAN GUIDELINES FOR SEISMIC VULNERABILITY ASSESSMENT OF POWER NETWORK INSTALLATIONS – ID 405

*B. Esmailzadeh Hakimi, Nirou research Institute, Iran (Islamic Republic Of)*
*A. Aghababai, Electric Power Research Center, Iran (Islamic Republic Of)*
*A. Taheri Moghadam, Electric Power Research Center, Iran (Islamic Republic Of)*

Although there is a great attraction for Structural and Earthquake Engineers to follow analytical and sophisticated methods to assess seismic vulnerability of structures and equipment but these lose their meaning in the shadow of large level of variation of earthquake characteristics and effects. Therefore methods based on past observations of failure modes may be followed better regarding complexity of industrial installations.

In this paper it is aimed to present the processes of development of National Iranian Guidelines for Seismic Vulnerability Assessment of Power Network Installations with regard to seismic safety requirements of economical and sociological situation of Iran and according to international references in relation to this subject.

## EARTHQUAKE MAGNIFICATION FACTORS FOR 4-LEGGED SELF-SUPPORTING TELECOMMUNICATION TOWERS – ID 411

*S. R. Massah, Iran University of Science & technology, Iran (Islamic Republic Of)*
*M. A. Barkhordari, Iran University of Science & technology, Iran (Islamic Republic Of)*
*G. Ghodrati Amiri, Iran University of Science & technology, Iran (Islamic Republic Of)*

Due to the rapid advances and developments in telecommunication industry, worldwide, the thorough and proper investigation into the seismic behavior of telecommunication towers has proven to be the most essential. The researchers in their studies have considered the effects of earthquake induced loads mostly on the trussed steel towers of triangular cross sections. The main objective of this paper is to obtain some approximate relations that could help the designer in evaluating the seismic response of 4-legged self-supporting telecommunication towers by determining their corresponding ground motion base shear and vertical amplification factors. For this purpose, eight of the existing telecommunication towers in Iran are considered for a modal superposition analysis under the effect of ten strong-motion earthquake accelerograms. Both longitudinal and vertical components of earthquake records have been taken into account. To obtain relations that would cover a vast range of earthquake zoning, the records are selected such that both near-field and far-field effects are included in the analysis. The suggested relations are presented as functions of the tower's largest flexural period or largest axial period of vibration, and can be applied by designers to only approximate the dynamic forces in such structures under seismic loadings.

Keywords: 4-legged telecommunications towers, amplification factors, base shear, vertical reaction

Contacts: massah@iust.ac.ir , barkhordari@iust.ac.ir , ghodrati@iust.ac.ir

## SISROUTE: EARTHQUAKE SCENARIO GENERATION SYSTEM ALONG ROADS (GLOBAL CONCEPT AND HAZARD ASSESSMENT) – ID 516

*A. M. Duval, CETE Méditerranée, France*

SISROUTE is a tool developed for the French Ministry of Transportations. It is designed to roughly assess road failure due to earthquake. Preparation of seismic crisis by local road managers is also aimed. The concept developed consists in linking, for each road, element "vulnerability" values together with "hazard" values, in order to produce for a given scenario, "risk" values relative to road failure possibilities. Data are involved in a dynamic geographical informatique system. SISROUTE concept had to overpass two antagonistic specifications of linear infrastructure scenario: the scale of survey should be large enough to be economic and simple, but a very small element can be responsible for road failure ... Hazard is expressed in term of maximum acceleration of soil (Amax), starting point of the risk analysis. The preparation of the system for each road consists in integrating constant hazard data concerning site effect and induced phenomena. A microzonation is realized using French building code soil classification. An amplification factor for Amax is applied to take into account site effect. A simple procedure is established to evaluate induced phenomena possibilities for each area. Critical values of Amax, that can "trigger" different induced phenomena are assessed. The other parts of the system preparation (described in 2 other papers) consist in assessment of the different vulnerability values for "vibrations" (Amax), liquefaction and landslides for all road elements. When a scenario is generated, Amax is evaluated all along the road according to one of the three patterns: French seismic zonation, probabilistic zonation or any earthquake defined by its location and magnitude. For each element of the road, hazard values are assessed (Amax, liquefaction, landslide) and combined with the corresponding vulnerability values. Resulting "risk" values represent road failure possibilities.

Maps are produced, pointing out road failure possibilities and causes for this scenario.

### EARTHQUAKE INDUCED PEAK GROUND STRAINS IN THE PRESENCE OF STRONG LATERAL SOIL HETEROGENEITIES – ID 550

*L. Scandella, Politecnico di Milano, Italy*
*R. Paolucci, Politecnico di Milano, Italy*

In the absence of earthquake induced permanent displacements and deformations, the seismic response of buried structures, such as tunnels or pipelines, mainly depends on the amplitude of transient strains induced in the ground. Transient strains and curvatures are a result of incoherent, or out of phase ground motion along their length, so that longitudinal deformations may dominate under seismic action rather than shear strains. Since a direct measure of strains is not generally available, simplified formulas relating peak ground strain to peak ground velocity are typically used. Simple solutions for free field ground strains as a result of P, S, and Rayleigh waves are available, but they are valid only for homogeneous soil properties, so that their use may be questionable, especially when the buried structure crosses strong lateral soil heterogeneities. We propose in this contribution a simplified formula relating longitudinal peak ground strain to peak ground velocity, that takes into account the average shear wave velocity of soil, the impedance contrast of sediments and rock, the average dipping angle of the bedrock and the relative position of the site with respect to the soil-rock interface at the surface. For this purpose a set of parametric 2D analyses were performed, based both on theoretical closed-form solutions and on numerical simulations with a spectral element code. The proposed formula is validated against 2D numerical solutions obtained for representative geological cross-sections in Catania and Thessaloniki, to asses its capability to capture the spatial variability of peak ground strains, especially close to the soil-rock interface.

### SIMPLIFIED MODELLING OF CONTINUOUS BURIED PIPELINES SUBJECT TO EARTHQUAKE FAULT RUPTURE – ID 559

*R. Paolucci, Politecnico di Milano, Italy*

After surveying the existing engineering methods for the seismic analysis of continous buried pieplines subject to faulting, mainly restricted to strike-slip conditions, a novel simple approach is presented to shed further light on the problem, and possibly to be applied to more general faulting styles, such as normal and reverse. The method is based on the minimization of the total dissipated energy during faulting, taking into account the basic factors that affect the problem, namely: a) the pipe yielding under axial and bending load, through the formation of plastic hinges and axial slip; b) the longitudinal friction across the pipe-soil boundary; c) the lateral resistance of soil. The advantages and drawbacks of the proposed method are highlighted through a comprehensive comparison with previous approaches and simplified formulas, as well as finite element calculations. Parametric analyses are also provided to assess the relative influence of the various parameters that affect the problem, as well as some examples of vulnerability functions useful for simplified evaluations of damage to pipelines during large earthquakes.

### ANALYSIS OF LIQUID STORAGE TANKS USING AN INTEGRAL EQUATION APPROACH – ID 629

*J. Habenberger, Bauhaus-University, Germany*

The current proposal of Eurocode 8, part 4 claims the consideration of the flexible, impulsive pressure component in the analysis of liquid storage tanks. In this paper an integral equation approach is used to calculate the modal decomposition of the shell-liquid-system. The kernel of the integral equation is represented by the Green's function of the cylindrical shell. It is derived from the general solution of the cylindrical shell given by Fluegge. The impulsive pressure distributions depend on the velocity of the tank wall and are expressed as Fourier series. The integral equation is solved by successive approximation. The achieved results are compared with those of Finite-Element-Calculations.

### ANALYSIS OF GLOBAL DAMAGE AND FUNCTIONING OF HIGHWAY SYSTEMS IN EARTHQUAKE CONDITIONS – ID 833

*D. Dojcinovski, Institute of Earth. Eng.&Engineering Seism., Macedonia*
*V. Mihailov, Institute of Earth. Eng.&Engineering Seism., Macedonia*

The strong earthquakes that occurred in the past undoubtedly pointed out the important role of the road network in elimination of the consequences of occurred earthquakes and normalization of the living conditions. The damages to the road network components (bridges, tunnels, retaining walls etc.) can induce disruption of the traffic flow and disturbance of the road functioning in the most critical moments immediately after an earthquake. From these reasons, the investigations in the field of earthquake engineering are directed toward (1) investigation of damage to road systems, (2) analysis of disturbance of functions and (3) methods for mitigation of the consequences based on exploring the nature and the reasons for occurrence of earthquakes as well as the structural elements of the road systems. The purpose of this is improvement of the functioning of the road network composed of a number of facilities affecting the performances of the entire system. The objective of this paper is to draw general conclusions on the behaviour of the road systems, i.e., define the global damage, the seismic performances and the functioning of these systems in earthquake conditions based on investigations related to analysis of seismic hazard and risk, vulnerability of structures and their importance. To that effect, certain models from the theory of probability and seismic scenarios have been used to simulate the earthquake effect. Due to the pronounced "spatial" character of the road systems in the analysis of the global damage and functioning of the road system, the GIS technology has been used. The results from these investigations are presented through a concrete case of the road network in Macedonia – a country with a relatively frequent seismic activity.

### NUMERICAL ANALYSIS OF BURIED LIFELINES EXPOSED TO EARTHQUAKE MOTION – ID 936

*R. Borsutzky, Institute of Applied Mechanics, TU Braunschweig, Germany*
*L. Lehmann, Institute of Applied Mechanics, TU Braunschweig, Germany*

In seismic-prone areas the earthquake resistance of lifelines plays a role of particular importance for civilisation. Seismic caused failure of lifelines can, e.g., result in destructive fires (Kobe, 1995) or lead to epidemics (El Salvador, 2001). Therefore, it is necessary to examine the dynamic behaviour of lifelines exact as possible to avoid disastrous failures.

In the proposed paper a two step methodology is presented to analyse the transient response of underground lifelines exposed to seismic wave propagation effects. The investigation of the dynamic behaviour of lifelines is based on a three-dimensional numerical model containing the pipeline as well as the surrounding soil. Because of the generally relatively small extensions of examined domains in engineering soil-structure interaction analyses the seismic wave propagation inside the domain is often neglected. Looking specifically at wave propagation phenomena this negligence is not advisable for structures with large extensions, like buried lifelines. The presented methodology is based on the Domain Reduction Method and contains two steps. In the first step a large scale analysis is performed where the seismic source and the entire wave propagation path to the analysed pipeline is taken into account. The computation of the complete seismic wave field is accomplished by Green's functions. In the second step only the near field of the pipeline is examined and excited by forces equivalent to the seismic source. The method used here is a hybrid Finite Element (FE) - Scaled Bound-

ary Finite Element (SBFE) scheme in time-domain. By the use of FEs the near field can be modelled in detail, while the description of the half-space through SBFEs represents an efficient way to fulfil Sommerfeld's radiation condition.

The presented method enables a realistic analysis of the dynamic behaviour of buried lifelines and provides a basis for their save and reliable design.

### EMERGENCY OPERATION AND DAMAGE ASSESSMENT FOR WATER SUPPLY SYSTEM IN TAIWAN FROM CHI-CHI EARTHQUAKE – ID 965

*B. J. Shih, National Science & Technology Center for Disas, Taiwan*
*W. S. Li, National Science & Technology Center for Disas, Taiwan*

In 1999 the Chi-Chi Earthquake (ML=7.3), the most devastating one during the 20th century occurred in Taiwan. Beside the death toll over 2,500 and US $10.7 billion direct property loss, the infrastructure's destruction such as lifeline systems had brought a major impact on livelihood and economic activity. According to the surveyed data announced by Taiwan government, the Chi-Chi Earthquake caused lots of damages in the water supply facilities and pipelines including as followings: Shih Kang Dam's partial failure by the tremendous fault's lifting, which damaged the tap water intake for Taichung Area; the destruction of First Fengyuan Water Purification Plant caused the disruption of water supply for about 700,000 households in the Taichung municipal area; the distribution pipeline networks in severely disastrous area suffered huge damages due to the excessive ground movement and dislocation. Therefore, the methodologies to minimize the damage of water supply systems after a major seismic event are crucial for the general public's daily lives and the un-interrupted productions of industries. As a consequence, the higher seismic design standard for the water plants and pipelines, the more effective techniques for earthquake loss estimation at early stage and the better countermeasures in advance are the goals that we have to develop for the future hazard mitigation. This paper first focuses on the earthquake damage and the emergency operation for water supply systems experiencing Chi-Chi Earthquake and then presents a GIS-based scenario simulation. The suggested strategies and countermeasures for the water supply systems based on scenario analysis and the experience of the past events will also be discussed as a lesson learned from the Chi-Chi Earthquake.

### FRAGILITY CURVES FOR BURIED PIPELINES – ID 994

*M. Alexoudi, AUTh, Greece*
*K. Kakderi, AUTh, Greece*
*K. Pitilakis, AUTh, Greece*

Several empirical relations were developed in the last years to describe pipeline damage from wave propagation and/or permanent ground deformation. The majority of existing fragility curves is based on data provided mainly from USA and Japan earthquakes that correlate damage with repair rate/km (RR/Km). In general, RR/km is connected in terms of peak ground velocity (PGV), peak ground accelerations (PGA), permanent ground displacement (PGD) and rarer with ground strains. However although in Europe several earthquakes had occurred, lifelines damage databases are very poor if non-existing. Recently, Lefkas earthquake (Greece, Ms=6.4, 14-8-2003), provided a detailed well documented pipeline damage database. Several empirical relations for wave propagation and permanent ground deformation were used and compared with observed and recorded pipeline damages. The aim of the paper is to evaluate empirical data of pipeline damages from Lefkas earthquake in Greece in order to improve existing fragility curves for ductile and brittle pipelines. PGV and PGD values have been estimated using available records during the earthquake and numerical ground response analysis. The spatial distribution of strong motion parameters and ground strains was calculated using a detailed and appropriate to the specific site conditions, 1D EQL site effect analysis. PGV and PGD values were compared with recorded damages in terms of Repair Ratio. Correlation between estimated PGV and ground strains was also used to compare RR/km for wave propagation with ground strains for brittle and ductile pipes. The results were compared with proposed relationships in HAZUS, ALA (2001), as well as recent relation derived from O'Rourke & Deyoe (2004) for ground strains. Comparisons between different experimental and other empirical fragility curves are discussed. The work presented herein is one of the first attempts in Europe to establish fragility curves for pipelines based on European distinctive characteristics of both ground motion and pipelines.

### EARTHQUAKE VULNERABILITY OF TELECOMMUNICATION NETWORKS – ID 1089

*S. Stiros, Dept. of Civil Eng., University of Patras, Greece*
*V. Kontogianni, Dept. of Civil Eng., University of Patras, Greece*
*P. Psimoulis, Dept. of Civil Eng., University of Patras, Greece*
*S. Pytharouli, Dept. of Civil Eng., University of Patras, Greece*

Numerous 20th century earthquakes have caused problems to telecommunications (T/C), mainly due to failure of T/C cables, but their effects were rather limited to small areas inside the meizoseismal zones. In the last 10 years, however, a number of seismic events caused serious problems to T/C, the pattern and role of which have become much more complicated and important, respectively, compared to the situation 20-30 years ago. In the framework of a Project sponsored by the Greek Secretariat for Research and Technology, and in cooperation with the Greek National T/C Organization (OTE SA), we investigated the impacts of earthquakes on the T/C networks and their corresponding vulnerability. The preliminary results of our study are first, that recent and future earthquakes affect T/C in much broader regions than in the past. And second, T/C networks are not affected only by the primary effects of earthquakes (mostly cable failure or tower collapse), but also their indirect, or domino-type effects: overloading of networks, even aborting the possibility of by-pass paths and leading to blackouts, local strong motions interrupting power supply, limitations in the serviceability of the network, etc.

### SEISMIC RISK ANALYSIS OF A LIFELINE SYSTEM SUBJECTED TO PERMANENT GROUND DEFORMATIONS – ID 1114

*J. Facciorusso, Dept. of Civil Eng., University of Firenze, Italy*
*T. Crespellani, Dept. of Civil Eng., University of Firenze, Italy*
*S. Renzi, Technical University "Carolo-Wilhelmina", Germany*

During earthquakes water facilities founded on soil deposits are subjected to displacements and differential movements induced by seismic waves passage (Transient Ground Deformations) or fault upgrading, soil liquefaction, densification, slope instabilities (Permanent Ground Deformations). Observations on seismic performance of water systems demonstrated that soil differential settlements and movements are the main cause of damage for water pipelines and that there is a level of soil displacements above which the induced ground movements can cause serious problems to the water system efficiency. In the present study a seismic risk analysis of the water facility system of the Municipality of Rimini (Italy) has been carried out by considering permanent ground deformations effects on the lifeline system. After a preliminary investigation, it was demonstrated that ground settlements caused by excess water pore pressures dissipation in saturated soils and volume changes in unsaturated soils are the most probable cause of damage for the considered facility system. A procedure for assessing water facility seismic vulnerability due to ground settlements is illustrated. The methodology, relying on performance-based design principles, consists of the following main steps: 1)selection of design earthquakes corresponding to rare maximum and more probable events; 2)assessment of water facility requirements in terms of allowable damage levels and soil deformations during the selected seismic events; 3)estimation of ground movements and displacements ; 4)evaluation of seismic effects of ground deformations on water lines in terms of induced stresses and strains; 5)comparison between water facilities requirements and settlement-induced effects on the water lines.

Ground settlements were estimated using a procedure suggested

by Yoshimine and Ishihara for saturated soils and a procedure realised by Pradel for unsaturated soils. Stress and strains induced by permanent ground deformations on water pipelines were calculated by means of the Liu and O'Rourke method.

### TOOLS TO DEVELOP CONTINGENCY PLANS AFTER AN EARTHQUAKE - THE MEXICO CITY'S WATER SYSTEM CASE – ID 1169

*O. A. Pineda Porras, Institute of Engineering, Mexico*

The main objective of this paper is to present a group of useful tools to develop contingency plans after an earthquake, for the Mexico City's Primary Water System (MCWS). These tools consist on: 1) the study of the relationship damage-intensity for the MCWS; 2) a comparison of the damage ratios for different pipe diameters; 3) the analysis of the influence of ground subsidence, typical in the Valley of Mexico, in the 1985 damage scenario; 4) a seismic microzonation; 5) the estimation of the possible serviceability indexes of the MCWS after future earthquakes; and finally, 6) the computation of the possible number of pipe repairs due to future Pacific coastal earthquakes. It is expected that these results, along with new seismic design criteria, are employed in the mitigation of the seismic impact and the development of contingency plans due to future earthquakes.

### EVALUATION OF METHODOLOGIES FOR THE DESIGN OF BURIED STEEL PIPELINES CROSSING ACTIVE SEISMIC FAULTS – ID 1242

*G. Bouckovalas, National Technical University of Athens, Greece*
*G. Kouretzis, National Technical University of Athens, Greece*
*V. Zania, National Technical University of Athens, Greece*
*E. Gavrielatou, National Technical University of Athens, Greece*

Strain analysis of buried steel pipelines due to the permanent displacement induced from the rupture of an active seismic fault crossing their route is probably the most critical aspect of their seismic design. The methodologies employed for such analyses can be classified into four categories: non-linear finite element analyses with shell elements, with beam elements, or with rod elements, as well as simplified analytical methodologies, with the one proposed by Kennedy et al. (1977) being the most widely used.

The computational cost as well as the accuracy of the results varies widely among the different methodologies thus, their range of use is a key issue that has not been systematically investigated so far.

Following a brief overview of the aforementioned methodologies, all four of them are employed in a series of comparative analyses for a typical high-pressure natural gas pipeline, constructed in a sand-filled trench. The routing of the pipeline is assumed to cross perpendicularly the trace of strike-slip, normal and reverse faults, with maximum expected displacement ranging form 0.4 to 2.4m.

From the comparison of the results, considering the analyses with shell elements to be the benchmark solution, it emerges that: -The methodology proposed by Kennedy et al. provides fairly accurate results only for large, i.e. over 1.2m, strike-slip and normal fault displacements, when strains in more than 50% of the area of the cross-section exceed the yield limit. Contrariwise, it fails to predict the response in the case of reverse faults. -Analyses with rod elements provide results similar to those of the Kennedy et al. methodology, as the bending stiffness of the pipeline is neglected. -Analyses with beam element are accurate only for small fault displacements, when the pipeline steel remains in the elastic range, whereas for larger fault displacements, strains are overestimated.

### AN ECONOMIC APPROACH TO LIFELINES INTERDEPENDENCIES FOR SEISMIC RISK ANALYSIS - THESSALONIKI'S PORT – ID 1243

*K. Kakderi, Aristotle University of Thessaloniki, Greece*
*M. Alexoudi, Aristotle University of Thessaloniki, Greece*
*K. Pitilakis, Aristotle University of Thessaloniki, Greece*

Lifelines are complex systems; each system's co and post seismic performance and functionality are determined by the seismic hazard, vulnerability and intraconnectedness of its elements, and interconnectedness with other external systems. Lifelines interdependencies are classified into different types, along with the proposed methodologies for their simulation. Ports are part of the transportation network; thus their operation in normal, crisis and recovery period is influenced by other lifeline systems, as they are composed of different structural and non structural components concentrated in a limited area. Quantifying the degree of lifeline dependences can lead to a more rigorous assessment of pre and post earthquake port risk mitigation actions. The aim of this research is to propose adequate interdependency indices between lifeline systems based on an "input-output model", in normal, crisis and recovery period. This model comprises a linear, deterministic, equilibrium approach and a framework capable of describing the degree of interconnectedness. The Port of Thessaloniki in Greece is used as an example. It is assumed that the level of economic dependency is the same as the level of physical dependency. Lifeline interactions are estimated based on consumption data on monetary terms. The latter refer to the consumption of a system's product from other lifeline systems (i.e. power supply to pumps) within the port's territory. Interdependency indices are calculated based on annual deviations of consumptions. These variations during monthly periods are supposed to reflect pre, co-seismic and post seismic lifeline synergies. The results show that seismic risk of lifelines is increased during the recovery period when interactions are considered. In crisis period, their influence depends on the specific system and hazard attributes. Estimation of interdependency lifeline matrices during different periods contributes to the establishment of an optimum recovery strategy and efficient seismic risk mitigation priorities.

### GAS PIPE DAMAGES AND LESSONS LEARNED IN THE 2004 MID NIIGATA EARTHQUAKE – ID 1293

*Y. Shimizu, Tokyo Gas Co., Ltd., Japan*
*F. Yamazaki, Chiba University, Japan*
*R. Isoyama, Japan Engineering Company, Japan*
*H. Shinkai, Tokyo Gas Co., Ltd., Japan*

The 2004 Mid Niigata Earthquake (6.8 JMA Magnitude) occurred on Oct. 23rd, 2004 at Niigata-ken located in the center part of JAPAN. The maximum observed SI values and PGA are 155 Kine and 1700 Gal respectively and lots of damages were found especially in lifeline networks such as water supply, electricity and city gas networks and service suspension was conducted for these lifeline systems. To cope with earthquake related secondary disasters, the city gas distributors made decision to shut off gas supply immediately after the earthquake and gas supply was interrupted at 56800 households. Actually, hundreds of damages were observed in screwed joint steel pipes which are usually used in low pressure city gas networks in Japan but quick decision on gas supply shut-off resulted in no gas leakage related secondary accident over this area. Tremendous efforts by JGA (Japan Gas Association) gas distributors were made for restoration of gas supply in hard hit areas but it took 38 days for full restoration. The cause of slow restoration was investigated thereafter and countermeasures against it were set up now, which are described in this report in detail.

### AN INVESTIGATION OF SEISMIC RISK ASSESSMENT IN LIFELINES, SPECIAL VIEW OF INTERCITY ROAD NETWORKS – ID 1339

*F. Yaghoobi Vayeghan, Transportation Research Institute (TRI), Iran (Islamic Republic Of)*
*M. Hosseini, IIEES, Iran (Islamic Republic Of)*
*M. Firoozi Nezamabadi, Islamic Azad University (IAU), Iran (Islamic Republic Of)*

As Iran is located in the high seismic area, assessment of seismic risk in lifelines, particularly transportation networks, is necessary. Intercity road networks, as a part of transportation networks, not only is one of the most important factors of sustain-

able development in countries, but also will be used for emergency management purposes after natural hazards, like earthquake, flood, hurricane and snow avalanche. In this paper, at first, some researches about seismic risk assessment of lifelines, like power and water transmission systems and also telecommunication networks, presents; then seismic risk assessment in intercity road networks – similarities and differences - will be discussed. Finally, by comparing between intercity road networks and the other lifelines, some basic strategies of risk management for intercity road networks, especially in Iran, will be recommend to be used by government and decision makers.

### A RESEARCH ON THE SEISMIC RELIABILITY EVALUATION ALGORITHM FOR LARGE SCALE LIFELINE NETWORKS – ID 1354

*J. Li, Tongji University, China*
*Y. Qian, Tongji University, China*
*W. Liu, Tongji University, China*

With the rapid development of modern cities, their dependences on the lifeline systems such as the water supply systems, the gas supply networks, increase gradually. The post-earthquake properties of lifeline engineering systems may directly determine the recovery of daily life as well as the efficiency of fighting the secondary disasters. To ensure the safety of lifeline systems suffering earthquake, it is of great necessity to analyze their seismic reliabilities.

As well known, Seismic reliability analysis of large scale lifeline networks is a typical 'NP-Hard' problem and it has been an important subject of considerable researches. Among those approaches, the minimal path-based Recursive Decomposition Algorithm developed recently is one of the most efficient methods. It can efficiently decrease the computation complexity and is senior to other algorithm in finding reliability of large scale networks. However, detailed investigations have shown that it may be inapplicable to network whose components have very low reliability. In this paper, by combining the recursive decomposition principle and minimal cut searching method, a new algorithm named as the minimal cut-based Recursive Decomposition Algorithm is proposed and successfully put into the reliability analysis of large scale lifeline network systems under strong earthquake. It is found that the algorithm presented in the paper can rapidly get the results for the networks with the components of lower reliability index. A seismic reliability analysis of a real large network, Shenyang city's gas supply network, is performed using the presented algorithm.

### STRESS ANALYSIS OF BURIED STEEL PIPELINES CROSSING ACTIVE STRIKE-SLIP FAULTS – ID 1454

*D. Karamitros, National Technical University of Athens, Greece*
*G. Bouckovalas, National Technical University of Athens, Greece*
*G. Kouretzis, National Technical University of Athens, Greece*

Existing analytical methods for the stress analysis of buried steel pipelines crossing active strike-slip faults are based on rather crude simplifications that limit their applicability and may, in some cases, lead to non-conservative results. A new analytical methodology is presented herein, taking into account the pipeline bending stiffness and the soil-pipeline interaction in both axial and transverse directions. The method employs a combination of beam-on-elastic-foundation and elastic beam theory for the calculation of bending strains. Geometric non-linearity due to second-order effects is indirectly taken into account in the calculations, while the actual distribution of stresses in the pipeline's cross-section is considered for the calculation of the design axial, bending and maximum strains. The effect of the non-linear behaviour of the pipeline steel is implemented on the essentially elastic beam analysis with the aid of an iterative procedure for calculating the secant Young's modulus, while considering a bilinear material stress-strain law.

Results of the proposed methodology are evaluated against the results of a series of benchmark 3-D non-linear numerical analyses with the Finite Element Method and compared to those of existing methodologies. The comparison between the analytical and the numerical results leads to conclusions concerning the validity of the assumptions of the existing analytical methods, which are proved in certain cases to be inapplicable. In contrast, the proposed methodology appears to be a strong alternative to Finite Element analyses, providing results that differentiate no more than 10% from the numerical ones, for the whole possible range of fault displacements. Its relatively simple calculation procedure can be easily programmed and could also be integrated in guidelines for the design of buried steel pipelines.

### EFFECT OF GROUND MOTION AND DAMAGE CORRELATION IN TRANSPORTATION NETWORK RISK ASSESSMENT – ID 1481

*R. Lee, Stanford University, United States*
*A. S. Kiremidjian, Stanford University, United States*

The performance of transportation network systems following an earthquake is critical for emergency response and economic recovery of the region. Risk assessment studies performed to date have included the losses from damage to critical components of the transportation system, such as bridges, tunnels and roadbeds, and losses from closure of links of the system due to failure or extensive damage to these components. Link closures result in traffic time delays and in lost trips which add to the losses from the overall system. In previous transportation network loss estimation studies the correlation of ground motion and damage to bridges has been ignored.

In this paper, the correlation of ground motion and bridge damage is modeled and included in the overall risk assessment of transportation network risk assessment formulation. Two approaches are presented in the risk formulation. The first is analytical and the second uses a Monte Carlo simulation approach. The Monte Carlo simulation approach uses an efficient algorithm to enable application to large transportation networks. Areas of correlation influence are considered for the ground motion correlation resulting in computational complexity.

The effect of these correlations is investigated as a function of the size of the network and is found that the uncertainty in loss estimates significantly increase with these correlations included. Furthermore, the uncertainty increases with increased network size. These results are obtained from applications to sample networks in the San Francisco Bay Region.

### SEISMIC DAMAGE ANALYSIS OF WATER NETWORKS – ID 1527

*M. Hooshmandzadeh, Islamic Azad University of Shushtar Branch, Iran (Islamic Republic Of)*

In this paper the response of water pipelines againstearthquake and seismic hazards are studied. As pipeline passes from wide areas , it may be affected by many seismic hazards. These hazards are such as ground rupture, fault movement ,landslides and large deformation due to liquefaction. Based on the past experiences ,damages to the water pipeline are classified and illustrated. This classification is based on the damagesof the pipe body,joints ,facilities and serviceability. Since the buried pipes are placed in loose grounds,their seismic response characteristics are different from buildindg or buried foundations.Effective factors of seismic behaviors of buried pipes are ground characteristics, earthquake characteristic and pipe structure condition. The response of pipes during earthquake, relation between damage and ground response such as nonuniform settlements and liquefaction are classified. The methods of settlement calculation and analytical models of piper response are also discussed. At the end , the latest results obtained from past earthquakes are classified.

### ESTIMATION OF SEISMIC RELIABILITY OF NETWORKS WITH SPATIALLY CORRELATED COMPONENTS – ID 1553

*S. Selcuk-Kestel, Illinois State University, United States*
*M. S. Yucemen, Middle East Technical University, Turkey*

Lifelines, such as gas and water distribution systems, highways are idealized as equivalent networks with the seismic capacity of their elements being random and spatially correlated. In the studies conducted by Selcuk and Yucemen (1999, 2000), the effect of spatial correlation was considered only within elements and the spatial correlation among different components is ignored. The spatial correlation between any two elements of the system will be a decaying function of the average distance separating them and is expected to depend on the correlation structure of the seismic capacity and demand.

This study aims at improving the previous studies of the authors (Selcuk and Yucemen, 1999, 2000) by incorporating the spatial correlation among the different elements of the network. The correlation matrix associated with the elements of the network is determined and the reliability bounds for real life applications are calculated under the assumption of spatial correlation among the different elements of the network. The comparison of reliability bounds calculated for the case studies will enable the decision-maker to evaluate the impact of the position of a component to an active seismic source and its neighboring components in the network. Therefore, the correlation coefficient matrix for pairs of components in the network will be the determinant of the reliability of the whole system. The stochastic model for the correlation coefficients based on the random distances will be an important tool of finding an optimum location to relocate a new component in the network after a destructive collapse.

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### A LOSS ANALYSIS METHOD AND EVALUATION FOR CORRELATED BRIDGES IN A TRANSPORTATION NETWORK – ID 1663

*R. Lee, Stanford University, United States*
*A. S. Kiremidjian, Stanford University, United States*

This study focuses on uncertainty specification in direct loss estimation for a spatially distributed transportation network. In particular, the effect of ground motion and damage correlation in the aggregate loss distribution is addressed. A sensitivity of the loss distribution to damage correlation under the assumption of an equi-correlated ground motion random field is considered. The loss distribution may be solved analytically under the assumption of independence by the convolution of individual loss probability distribution functions (pdf). Dependence in loss distributions, as a result of correlation effects in ground motion and damage random variables, may be treated in a like manner after transformations to uncorrelated random variables. The form of the loss distribution is investigated via Monte Carlo simulation when there is dependence in ground motion and in damage and when the damage factor and replacement cost of individual bridges are introduced as further sources of uncertainty to loss. Moreover, the importance of incorporating correlation effects is emphasized by observed changes to system reliability. System failure for a sample network is estimated through first order reliability (FORM) method. The sensitivity of system reliability to increasing levels of ground motion and damage correlation is reported for a sample application.

## ES 8 & ES 7: Earthquake Engineering Practice (Recent Projects) and Architectural Aspects, Nonstructural Components and Contents (Joint Session)

Level-1

### PARAMETRIC SYSTEM IDENTIFICATION TECHNIQUE FOR DAMAGE DETECTION OF MULTISTOREYED SHEAR BUILDING – ID 61

*A. Dutta, Indian Institute of Technology, India*
*S. K. Deb, Indian Institute of Technology, India*
*M. Medhi, Indian Institute of Technology, India*

The present work utilizes system identification technique for damage detection of shear building, wherein Parametric State Space modeling has been adopted. The objective is to identify damage through detection of stiffness changes in multistoreyed shear building. Considering floor acceleration response data from different floor levels of a numerically simulated building in both undamaged and damaged state as output and earthquake ground motion data as input, parametric system identification using State Space Model of the structure has been carried out. The extracted modal matrix for the entire structure has been utilized for the evaluation of structural stiffness matrix using least square technique. Thus, by applying this strategy to both undamaged and damaged floor acceleration response data, the identification of the damage location as well as the evaluation of extent of damage could be very efficiently carried out through the comparison of structural stiffness matrices obtained corresponding to both the cases. Highly accurate values of stiffness of the structure could be evaluated corresponding to both undamaged as well as damaged states of a structure. Further, in case of limited availability of sensors along the height of a multi-storey building, the methodology could yield very accurate information related to structural stiffness. The procedure is directly useful to be applied for the real time structure subjected to earthquake excitation and structural damages can be very efficiently identified by collecting acceleration response data from some sensors located at different floor levels. The Holzer's Criteria could be used to overcome the problem of limited number of sensors for the extraction of full modal matrix of a structure.

### SEISMIC INVESTIGATION SITING PROCESS FOR A CERCLA WASTE DISPOSAL FACILITY – ID 69

*T. Schacher, EPFL (to be confirmed), Switzerland*
*J. Beavers, University of Tennessee, United States*

This paper presents a brief overview of the seismic investigation for siting a potential Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Waste Disposal Facility near the New Madrid Seismic Zone in the Intraplate Region of the United States. The author was a consultant to the United States Department of Energy for siting and developing the seismic criteria for the Waste Disposal Facility to be used for indefinite storage of the remnants of future demolition of the uranium enrichment plant near Paducah Kentucky. The site was located 100 km from the epicenter of the February 7, 1812 earthquake, one of three potentially great earthquakes that occurred December 16, 1811 to February 7, 1812. The area is the highest seismically active region in the United States east of the Rocky Mountains.

The United States Environmental Protection Agency's (EPA) seismic design requirements for waste disposal facilities are they be designed for an earthquake ground motion that has a 2,500 return period and the foot print extremities of the facility must be 61 meters from the location of a Holocene fault. Based on the United States Geological Survey, the seismic hazard ground motion for the proposed site was established at 2.55g at a B/C boundary condition.

Establishing the seismic hazard included a project team assessment to provide answers to the following: (1) Is there evidence of paleoliquefaction at or near the site?; (2) Is there paleoseismic evidence of local strong ground motion?; (3) Is there potential for

future liquefaction at the site?; (4) Is there evidence of Holocene displacement of faults at the site?; (5) Are there faults underlying the site?; (6) What is the peak ground acceleration design value at the site?; and (7) What are the characteristics for the design ground motion?

### SEISMIC VULNERABILITY ASSESSMENT OF NON STRUCTURAL ELEMENTS IN A THERMAL POWER PLANT – ID 209

*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*
*A. Rezaie, ERC-TEHRAN, Iran (Islamic Republic Of)*

Non Structural elements such as mechanical, electrical and architectural elements always posses serious damage potentials during earthquakes. Degree of damage imposed by the non structural elements is not usually measured by the physical damages caused, but more so by the amount of the economical and functional disruptions created in a built environment. This phenomenon is enhanced where the functional performance criteria used for the specific site should be of higher standards, meaning for example the "immediate use" conditions.

In order to account for this sort of possible interruptions and plan for the worst case scenario during an earthquake in a thermal power plant in Iran, a study was carried out to evaluate the seismic vulnerability status of the mechanical, electrical and architectural components of the main control building in this power plant. Level one and two assessment methods, namely; rapid and detailed evaluations were used. Two main documents considered for this study were the MCCER manual and FEMA-310 evaluation forms. Some modifications were also performed to calibrate the procedures to local conditions. Parameters such as anchorage, load path, interaction, support conditions, pounding impact and vibration isolator concerns were among other factors investigated.

The method used and results obtained which are classified into four hazard levels meaning, very high, high, intermediate and low will be presented in this paper.

### DYNAMIC ANALYSIS OF INTERCONNECTED EQUIPMENTS ALLOWED TO UP-LIFT – ID 261

*M. Ghafory-Ashtiany, IIEES, Iran (Islamic Republic Of)*
*V. Sharif, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iran (Islamic Republic Of)*

This paper provides fragility analysis of interconnected block-type equipments which exist in most industrial complexes and their responses are of major interest in seismic vulnerability analysis of industrial equipments. Block-Type equipment under earthquake loads can be modeled as a rigid block resting on supporting basis. Considering the fact that most of the equipments are interconnected, rather than standing alone, it is necessary to include interconnection effects in response of all equipments. A new mathematical model which covers various type of rocking motion and up-lift has been developed with the consideration of its geometrical nonlinearity because of large deformation of blocks, as well as rigid and/or flexible base condition. The paper also provides the numerical results of the equipment behavior for various earthquake inputs. The results show the importance of the interconnections consideration of the block-type equipments in the response behavior.

### CHALLENGES TO HISTORIC REINFORCED CONCRETE HOUSING ARCHITECTURE IN EARTHQUAKE PRONE AREAS OF EUROPE – ID 457

*M. Bostenaru Dan, ROSE School, Italy*
*R. Pinho, Università degli Studi di Pavia, Italy*

Sustainability issues have formed the public idea that a kind of fortification leading to intensive development of towns inside an area delimitated within the surrounding nature is necessary. While in the majority of cases this means upgrading existing buildings to changed living standards, earthquake prone countries face the challenge given by safety standard requirements. The project will contribute to the documentation of the reinforced concrete housing buildings of the Modern Movement, by analysing the distribution of this building type, with comparative studies regarding the differences in the architectural language adopted for as well as changes induced by preservation requirements on buildings of this type in areas of high/low seismicity, and their determinant factors (earthquake hazard, urban development policies); existing attempts and distribution determined need for seismic rehabilitation; the time when this type of construction reached the respective countries, and the subsequent relationship to codes and the earthquakes affecting; the suitability of certain methods for buildings situated in different ranges of cultural value. A buildingtypological study was performed, and criteria in order to facilitate the dialogue among the actors in assessment developed. Out of those investigated so far, Romania, Greece, Portugal, Slovenia, Spain and Italy are regions prone to earthquakes, to variable extent, and some shared a common housing typology in the early XXth century. Multidisciplinary research interferences are: sociology/architecture, technology/architectural/economic, geophysical/urbanistic, structural/technology/architecture. Results from previous research will flow into the project transdisciplinarily. The project addresses the way how to enhance the acceptance for measures towards reduction of seismic risk. Possibilities of dialogue with citizens are investigated in the research on participative aspects in decision making, using the method of documentation of examples of best practice. This project is funded as Marie Curie Intra-European Fellowship by the European Commission, contract nr. MEIF-CT-2005-009765.

### SEISMIC EVALUATION AND RETROFIT OF REFINERY HEATERS – ID 492

*H. Kazem, NIOEC, Iran (Islamic Republic Of)*

Design concept and construction procedures of refinery installation similar to other engineering systems are going to improve and on the other hand many different parameters such as environmental situations, maintenance situation and their losses during its activities may damage the process activities. In this case the vulnerability of refinery equipments that are designed according to the existing codes, are very important. Heaters in the refineries are the most important equipment that converts crude oil to refining oil. In the refineries, equipment such as heaters is made of three components such as pipes, main bodies and stack. Inside the heater the heat transferred to the pipes. Since the heaters have special geometries and should have resistance against earthquake, therefore special computer calculations and software such as ANSYS program is used and with the aids of final results, the damage mechanism of the heaters can be predicted. The most important of failure modes of heaters in the past earthquakes are failure due to supporting structures, overturning, incomplete stability, insufficient of earth connections, insufficient of bolts at the connection to the foundation and weakness in foundation and soil beneath it. For determining the real behavior of heaters, a typical real heater in one of the refineries (heater No.701) with its inside temperature 398°C considered as a case study. The heater is made of two stacks with its height of 59.6 meter, which is attached to the main supporting structure. A lateral bracing system is considered for the heater. The results obtained from static analysis, modal analysis and site spectrum analysis denotes that the displacement, sliding and overturning of the heater is in good conditions, but, stresses in the wall and foundation is overstressed and the strengthening methods should be used. Finally, retrofit calculations and design detail have been presented.

### RECONSTRUCTION OF THE HOLY VIRGIN ORTHODOX CHURCH IN SKOPJE – ID 529

*M. Garevski, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*
*V. Sendova, Institute of Earthquake Eng. and Eng. Seismology, Macedonia*
*B. Stojanoski, Institute of Earthquake Eng. and Eng. Seismology,*

*Macedonia*

The orthodox cathedral church of the Holy Virgin dating back to 1835 which was built by the most eminent Macedonian and Balkan builder Andreja Damjanov was put on fire in 1943 and later it was torn to the ground. On the initiative of the established Board for Rennovation of this church and due to the importance that it has ever had for the citizens of Skopje, the Skopje Metropolitan's Residence passed a resolution on the reconstruction of the church of the Holy Virgin in 2003. Based on the adopted appearance of the renewed church, IZIIS, Skopje elaborated the main project on the reconstruction of the church containing definition of the principal structural system, definition of the foundation conditions over the existing foundation and their consolidation as well as detailed static and dynamic analysis. The reconstruction of the church is being done with consideration of its authentic appearance, its previous location and over the existing authentic foundation. The main specificity of the structural system arising from the priorities regarding the appearance of the church on one hand and its seismic safety on the other is the solution of the three-layered bearing facade massive walls. On the inner side, these are constructed of solid bricks in cement lime mortar, while on the external side, these are constructed of crushed and hewn stone in cement lime mortar. In the middle part, a continuous reinforced concrete wall is envisaged. The performed detailed analysis has led to the general conclusion that such designed structure of the church of the Holy Virgin completely satisfies the prescribed requirements and criteria for such type of structures of special importance. At the last Symposium of the Macedonian Association of Structural Engineers this project was proclaimed the best achievement in the field of design in Republic of Macedonia in 2004.

## SEISMIC STRENGTHENING OF A LOW RISE STEEL FRAMED SCHOOL – ID 588

*H. Kazem, IAU, Iran (Islamic Republic Of)*
*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*

With the knowledge of constant treat of major earthquakes and especially the latest dramatic and catastrophic earthquake of southern city of Bam in Iran in 2003, a multi –disciplinary program was lunched in Iran to assess the seismic vulnerability of important buildings and possibly offer cost –effective strengthening solutions for the ones in need . In this program, noted emphasis was placed on schools, due to very poor behavior of schools during Bam earthquake. This paper is to present the methodology used to achieve the objectives of the project by considering qualitative and quantitative procedures. A general evaluation form was designed for screening considerations, different sections of the school. Structure was then opened and as built drawings was established. NDT tests were used and some material tests also were conducted to account for the possible differences with the original design parameters. Based on that a 3D model was constructed and linear and static nonlinear analysis was performed. Based on the analysis, critical damage indexes and envelope of critical loads were determined. Upon weak –link identification, cost effective schemes were proposed for strengthening considerations. Before and after retrofitting application, behavior was calculated for each schemes considered. Based on the best performance by the specific scheme considered, the final upgrading methodology was decided. In this paper also, methodology and details utilized for upgrading. A low rise steel framed school in Tehran, Iran will be discussed.

## SEISMIC EVALUATION AND STRENGTHENING OF AN HISTORIC SYNAGOGUE USING TRADITIONAL AND INNOVATIVE METHODS AND MATERIALS – ID 701

*T. Paret, Wiss, Janney, Elstner Associates, Inc., United States*
*S. Freeman, Wiss, Janney, Elstner Associates, Inc., United States*
*G. Searer, Wiss, Janney, Elstner Associates, Inc., United States*
*M. Hachem, Wiss, Janney, Elstner Associates, Inc., United States*
*U. Gilmartin, Wiss, Janney, Elstner Associates, Inc., United States*

A monumental 100-year-old multi-story brick masonry synagogue in San Francisco was threatened with closure due to non-compliance with an Unreinforced Masonry Building Ordinance. The Ordinance required demonstrating that the building would protect life safety in the event of a major earthquake or upgrading the building to do so, despite the historical record showing that the building survived the Great 1906 Earthquake with little damage. The minor damage that did occur is still visible today as the historic finishes have remained intact since that earthquake.

The structure consists primarily of thick, brick masonry perimeter walls, wood framed diaphragms with diagonal and straight sheathing, and riveted structural steel trusses and columns that support the domes over the main sanctuary. The structure was subjected to linear dynamic and nonlinear static analyses to benchmark its behavior during the 1906 earthquake, to better understand its vulnerabilities in the event of potentially stronger shaking, and to develop seismic improvements that preserve its ornately detailed stone and painted plaster finishes.

The most appropriate structural solution consistent with preserving the historic fabric takes advantage of the dynamic separation between the modes predominated by in-plane and out-of-plane wall shaking. The out-of-plane wall modes have long periods and have low modal mass participation. The solution consisted of a combination of intervention techniques, each developed to minimize disturbance to the nonstructural finishes, yet retain the original dynamic characteristics. These interventions include a system of tension ties in the attic that interconnects the four perimeter walls, yet circumvents the domed sanctuary; center-cored reinforcement of the masonry walls; and fiber-wrap. The tension ties contain super-elastic nitinol wires and were designed to be lightweight, easy to install, and to prevent the walls from falling outward while maintaining the inherent flexibility of the system that enabled the structure to survive the 1906 earthquake.

## AN EXPERIMENTAL ANALYSIS ON THE SEISMIC SAFEGUARD OF ART OBJECTS – ID 857

*M. Monaco, Faculty of Architecture Second University Naples, Italy*
*M. Guadagnuolo, Faculty of Architecture Second University Naples, Italy*
*M. Landolfi, Faculty of Architecture Second University Naples, Italy*

The problem of reducing the seismic risk for art objects, that is, the objects generally contained within Museums, is of great interest. The first studies were performed in Japan and were successively organized in a general framework by a research program performed at Southern California University and sponsored by the Getty Museum at Malibu, California. In these papers and in the following Italian studies, the theoretical models for the problem are based on the dynamic behaviour of rigid blocks and have been deeply developed. Unfortunately, because of the great lack of experimental data, determinant parameters for the characterization of the problem (like the friction between two superimposed blocks or between the art object and the support plane) are often assumed without reference to laboratory tests. This paper presents the results of a research program containing the experimental determination of the friction coefficient between the art object and the support (by means of a testing apparatus ad hoc realized) together with dynamic tests performed on simple shaped objects made of different materials. The dynamic tests were performed using an unidirectional shaking table and different supporting surfaces, so that he influence of different friction coefficients have been analyzed.

## SEISMIC DESIGN ALLOWING FOUNDATION UPLIFT (ROCKING) - A CASE STUDY – ID 1143

*E. Ko, Arup, United States*
*C. Field, Arup, United States*

This paper offers a comprehensive overview of the seismic design criteria and approach being employed in the construction of the new California Academy of Sciences (CAS) Building in San Francisco, California. The new CAS will incorporate three new 3-story buildings; one existing 2-story building; and an Exhibit

Area, which includes two large spheres housing the Planetarium and the Rainforest. The piazza floor slab is fully contiguous and interconnects the four buildings. The entire structure will be enclosed by a "green" undulating grass-covered roof. Once completed, the 370,000 square foot CAS building will be the only museum in the US to house a planetarium, aquarium, rainforest and research facilities under one roof.

A standard code approach required the use of ground anchors to prevent the building from overturning during a seismic event. This paper details the methods used by Arup engineers to validate the removal of such anchors and allowing the building to rock during a seismic event. Using fundamental design principals, it was determined that the undulating roof, supported by the four main building components, would remain stable when subject to earthquake forces. Non-linear dynamic time history analyses were employed to prove that the global behavior of the building was not significantly affected by permitting limited uplift of the foundation. The paper further discusses the performance benefits of adopting this innovative approach and the significant reduction in foundation costs which resulted from the elimination of ground anchors.

### SAFEGUARDING ARCHITECTURAL HERITAGE: ANCIENT ANTISEISMIC TECHNIQUES NEW APPROACH – ID 1386

*B. Carpani, ENEA, Italy*
*M. Indirli, ENEA, Italy*

Safeguarding Architectural Archaeological Heritage (AAH) in areas subjected to earthquakes is a hard problem to face, both for the difficulty to define appropriate intervention strategies, and the huge amount of valuable AAH structures to be improved. Even if AAH needs high protection level from earthquakes, in order to hand down it to posterity, specific conservation criteria often conflict with modern antiseismic requirements. Another keynote regards seismic hazard definition. If frequent moderate seismic events cause severe damage, rare strong earthquakes can induce complete disruption. Consequently, a probabilistic approach identifying the seismic input could turn out inadequate, while deterministic scenarios take into account earthquakes with high return periods. Nowadays, it is commonly accepted that antiseismic "compatible" interventions must firstly match conservation criteria as far as possible, bringing AAH monuments to their previous stability, respecting original structure without changing the overall static and dynamic behaviour. In fact, analyzing post-earthquake damage patterns, several historical constructions, if well done (i.e. constructed applying the "regola dell'arte") and kept in good maintenance, can support seismic loads with reasonable damage. Then, improving technologies can be applied, if congruent with the above mentioned rules. Moreover, because AAH characteristics (material properties, construction aspects, state of integrity) are frequently not very well known, seismic rehabilitation always needs preliminary accurate analyses, aiming at focusing the ancient builders "lexicon", identifying construction typologies and techniques with antiseismic effectiveness, due to the secular interaction between environmental and anthropic factors. So, investigations based on Architectural Archaeology (building study through the reading of its time stratifications) and Archaeosismology (construction seismic history) are therefore necessary. The paper shows examples of AAH monuments realized with systems incorporating original historic antiseismic techniques, often including modern engineering principles. Seismic input definition and improvement strategies are also discussed.

### VIBRATION PRONE NONSTRUCTURAL COMPONENTS IN ELASTIC-PLASTIC BUILDINGS SUBJECTED TO SEISMIC EXCITATION – ID 1624

*C. Adam, Vienna University of Technology, Austria*

Non-structural elements denote those components of a building that are not part of the main structural system but may also be subjected to seismic excitation. It is widely recognized that damage of non-structural components may seriously impair a building's function. The majority of the research is concerned with linear elastic structures without taking into consideration the fact that most of the structures to which non-structural elements are attached are designed to yield under the effects of a strong earthquake. As pointed out in the literature the non-linear behavior of the load bearing structure may significantly affect the non-structural elements. In the study summarized in the paper for selected MDOF structures, i.e. 3-story to 18-story generic frames composed of elastic columns and bilinear elastic-plastic springs at their corners, and non-structural elements modeled as SDOF oscillators with linear and elastic-plastic spring properties, interaction and detuning effects caused inelastic material behavior between both substructures are worked out in detail. Diagrams exhibiting the peak displacement as well the 84 percentile displacement history of the main structure and the non-structural system are presented as a function of the initial period of the non-structural element for several ground motion intensities. These diagrams are derived from a set of numerical studies involving 40 ground motions. The ground motions are scaled to the fundamental period of the primary structure. Results of this study are valid only for non-deteriorating hysteretic systems, i.e. systems in which strength deterioration due to excessive deformations or cyclic loading is not considered.

## STS E1 & SS 6: The Last Mile, Implementation of Risk Mitigation Measures in Europe

Level-1

### ACTIVITIES INITIATED BY BUET-VPI LINKAGE PROJECT ON SEISMIC VULNERABILITY IN BANGLADESH – ID 84

*M. Ansary, BUET, Bangladesh*
*A. Azad, BUET, Bangladesh*
*F. Krimgold, VPI, United States*
*S. Rahman, VPI, United States*

Urban development has been progressing rapidly in Bangladesh without the development of proper disaster prevention systems against potential earthquakes. Bilham et al. has pointed out that the zone may be a seismic gap that is accumulating stress, and that a huge earthquake could occur someday when the stress is relieved. It is urgently necessary to prepare a comprehensive earthquake disaster prevention plan.

The current project is a USAID, Bangladesh initiative to reduce vulnerabilities of communities in some of the most hazard prone cities of Bangladesh (Dhaka, Sylhet, Chittagong). The Project (2004-2008) aims to create awareness through local level to national level, enable them to minimize losses to development gains and to reduce their vulnerability to natural disasters. The major concerns of the initiatives are assessing the human resource capacity regarding earthquake issues, vulnerability analysis of buildings, dissemination of earthquake awareness at local communities etc. The project relies upon a community based approach to earthquake disaster management, and seeks to build capacities of communities, government functionaries at all levels, and other stake-holders in disaster management, at all levels, in an organised manner.

This project aims to assess the capacities of communities and local administration at urban level in Bangladesh. The project would demonstrate a suitable model to mainstream the earthquake risk management initiatives at all levels and help to reduce earthquake risk in the most earthquake-prone urban areas in Bangladesh. Urban Planning Institutions and other relevant agencies in the selected cities would be directly involved in the planning process to ensure sustainability of these initiatives. This project will work closely with relevant organizations and institutions at the National and Local levels. Learning from this initiative will be fed into the development of Community Based Disaster Risk Management Plan at Local levels and will help to mainstream training in earthquake disaster.

### PROPOSAL FOR SAFER BUILDINGS AND HOUSING AGAINST EARTHQUAKE IN DEVELOPING COUNTRIES : LEARNING FROM NORTHERN PAKISTAN EARTHQUAKE 2005 – ID 266

*T. Narafu, Building Research Institute, Japan, Japan*
*M. Inukai, National Institute for Land and Infrastructure Man, Japan*

We experienced another tragic seismic event in Pakistan on Oct. 8, 2005, which caused casualties of more than 73,000 and an enormous number of the injured. It reminded us again the huge risk of damages by large-scale earthquakes especially in developing countries. I participated in a survey team dispatched by Japanese Government immediately after the event and carried out on-site survey on damages of buildings and housing in Balakot, Mansehra, Abbotabad and Islamabad and interviews in the ministries relevant to Building Codes such as Ministry of Housing and Works (MOHW), Ministry of Environment (MOE), Capital Development Authority (CDA), Geological Survey of Pakistan (GSP)and others. I learned that vulnerabilities of building and housing come from various aspects such as technical aspects of Building Codes, incomplete enforcement both in administrative and practice, insufficient dissemination of seismic technologies to societies, poor quality of construction work like low quality materials, lack of quality control, poor skills of labors and convinced that comprehensive approach(not only technical but also social, economical and cultural aspects) is required to mitigate damages of buildings and housing and also that another different approach for non-engineered housing should be explored since formal regulatory institutions like building codes do not function well in this field. This paper reports the damages of building and housing, analysis on them, Building Codes and the enforcement in Pakistan based on the results of the on-site survey and proposes comprehensive strategies for safer building and housing, which are expected to be inputs for discussions on one of the most keen issues for safer living environment in developing countries among researchers, people in practice, administration, donor communities and people in relevant fields.

### OUTCOME OF SEISMIC MICROZONATION MAPS FOR THE DESIGN OF BUILDINGS – ID 541

*F. Widmer, Federal office for the environnement, Switzerland*
*O. Lateltin, Federal office for the environnement, Switzerland*
*J. D. Rouiller, Cantonal administration, Switzerland*

Seismic microzonation aims to take into account the important influence of local geology and topography in the determination of the seismic solicitations for the design of structures. In the application of building codes, this aspect is usually covered by assigning a soil class and corresponding code defined response spectrum to the building location. The new Swiss building code SIA 261 corresponds to a simplified and adapted version of Eurocode 8 for Switzerland. Two different types or levels of microzonation are used in Switzerland: the first level (called « microzonation according to SIA 261 ») is based on the seismic zonation map of Switzerland coupled with standardized maps of foundation soil classes as defined in the building code SIA 261. The second level (« spectral microzonation ») requires in-depth quantitative investigations of soil properties as well as wave propagation simulations. They are usually only performed for high risk potential sectors or objects. These studies provide site specific elastic response spectra, which are then used by the engineers in lieu of the code spectra. In Switzerland, many soil maps have been established since 2002. Theses maps are represented at a scale of 1:25'000. Approximately 40 maps have now been produced, and 20 new maps are planned until 2010, in order to cover 80% of the Swiss population. These maps of foundation soil classes are public and can be used for the seismic design of new constructions, as well as for the evaluation of the seismic safety of existing buildings. Several cantonal administrative procedures integrate these maps in the process of the verification of the seismic design of new buildings for the delivery of construction permits, or in the seismic verification of high risk existing objects. These maps can be interactively displayed on a specific Website, and therefore brought to a wide public.

### SEISMIC BUILDING MONITORING OF MULTISTORY RC STRUCTURES IN TURKEY - A CONTRIBUTION TO THE SERAMAR PROJECT – ID 2049

*J. Schwarz, Bauhaus-Universität, Germany*
*D. H. Lang, Bauhaus-Universität, Germany*
*L. Abrahamczyk, Bauhaus-Universität, Germany*
*W. Bolleter, SYSCOM Instruments SA, Switzerland*
*C. Savary, SYSCOM Instruments SA, Switzerland*
*M. Bikçe, Mustafa Kemal University, Faculty of Engineering, Turkey*
*M. C. Genes, Mustafa Kemal University, Faculty of Engineering, Turkey*
*S. Kaçin, Mustafa Kemal University, Faculty of Engineering, Turkey*

Recent damaging earthquakes in Turkey have shown, that not only the Marmara region around the megacity Istanbul is exposed to a high seismic risk. Since most of the international microzonation projects are concentrated on the Marmara region, there is an urgent need to center on alternative high-seismicity regions, such as the South-Anatolian province Hatay. In fall 2004, the Turkish-German-Turkish joint project SERAMAR (Seismic Risk Assessment and Mitigation in the Antakya-Maras-Region) started in the province capital Antakya, an ancient city of 150,000 inhabitants in the southernmost tip of Turkey. Judging by historical precedence, major earthquakes on this branch of the Dead Sea-East Anatolian fault system have a real potential for occurrence in the city. The main objective of the project, which is partly sponsored by the Swiss Agency for Development and Cooperation (SDC) is the thorough microzonation of an urban area in the forefront of a damaging seismic event. Thereby the assessment of seismic hazard and the identification of the local building stock's vulnerability is conducted in order to propose strategies for risk mitigation. In this context, the instrumental investigation of buildings being representative for the respective settlement area becomes an essential part of the project. Based on different selection criteria, three multistory RC structures were chosen and equipped with Seismic Building Monitoring Systems (BMS) generously provided by SYSCOM Instruments SA. A BMS consists of four triaxial strong-motion accelerometers (type MR2002+), of which three instruments are installed at different floor levels and one at the outside of the building (free-field-station). The major task of the long-term instrumentation is to obtain realistic data on the structural response due to earthquake shaking, and thus to identify weak points of the structural system, to elaborate the structural vulnerability, and to allow a calibration of the analytical building models as well as nonlinear analysis methods.

## STS E5: Eurocode 8 : How to Apply ?
Level-1

### SEISMIC ANALYSIS OF REINFORCED CONCRETE COUPLED SYSTEMS CONSIDERING DUCTILITY EFFECTS IN ACCORDANCE – ID 852

*J. Kralik, Slovak University of Technology, Slovakia (Slovak Republic)*
*R. Tínes, Slovak University of Technology, Slovakia (Slovak Republic)*

This paper presents results of experimental and numerical analysis of seismic resistance of reinforced concrete coupling system considering the plastic capacity in accordance of standard requirements STN P ENV 1998, PrEN 1998 (2003) and Önorm B4015 (2002). The plastic capacity of the structure can be established by parameter q in the case of the spectral analysis to determine the seismic response. The experience from dynamic analysis of a original and upgraded hospital structure in accordance with standard requirements is presented in this paper. Dynamic parameters of the building structure are checked by experiment and

the calculation model is modified on the basis of the experiment. The new seismic-resistant construction standards PrEN 1998 (2003) and STN P ENV 1998 enable to consider the seismic load effect to structures with regard to their partial damage, eventually collapse. With respect to computational and economical complexity there was a method established, which permits to transform a nonlinear dynamic calculation to a linear domain. Ductility factor is well described in standards, although nonessential ignorance of physical background could tend to incorrect results and performance errors (Flesch 1993). Incorrect and unsuitable interpretation can occur especially when hybrid structural systems, irregular geometry shapes and masses are considered. The framework of the hospital facility consists of the combination of frames, shear walls and a core wall system. Nonlinear analyses of walls coupled with frames were realized by software called CRACK under system ANSYS. Factors of the behavior, described in recent standards, are in case of some irregular structures unsuitably defined. The performance of those values would result into incorrect conclusions, as the article's shown. The nonlinear analysis, of the 2D critical substructures (wall, frame, core wall,..) subjected to the quasi load, presents the acceptable accurate view of its resistance.

### REAL EARTHQUAKE TIME HISTORIES SCALING TO SATISFY THE EUROCODE 8 SELECTION CRITERIA – ID 1842

*Z. Ozdemir, KOERI-Bogazici University, Turkey*
*Y. M. Fahjan, KOERI-Bogazici University, Turkey*

Due to rapid developments in structural analysis and computational facilities, time-history analysis is becoming more common in seismic analysis and design of structures. The crucial issues of such analysis are the selection and scaling of acceleration time histories to satisfy design response spectrum at a specific site. In literature, there are three sources of acceleration time histories: design response spectrum compatible artificial records, synthetic records obtained from seismological models and accelerograms recorded in real earthquakes. Due to the increase of available strong ground motion database, using and scaling real recorded accelerograms is becoming one of the most contemporary research issues in this field.

Eurocode 8 permits using of recorded accelerograms for earthquake time history analysis. A minimum of 3 accelerograms should be used where the mean of the zero period spectral response acceleration values should not be smaller than the value of ag.S for the site in question. The mean values of 5% damping elastic spectrum, calculated from all time histories, should not be less than 90% of the corresponding values of the code elastic response spectrum at periods range between 0,2T1 and 2T1, where T1 is the fundamental period of the structure. In Eurocode 8, the shape of horizontal elastic response spectrum is defined by four branches using the values of the periods TB, TC and TD which take varying values for the five local site classes A, B, C, D, and E and two ranges of earthquake magnitudes.

In this study, time domain scaling procedure is utilized to scale the available real records in existing database to match the proposed elastic design spectrum given in the Eurocode 8 for different seismic regions and soil types. The best fitted ground motion time histories are selected and classified taken into account the earthquake magnitude, focal mechanism, site conditions and fault to site distance.

## STS E9: Analysis and Design of RC Frames with Masonry Infills

Level-1

### CRACKING STRENGTH OF INFILLED FRAMES AND BOND BEAM DESIGNING METHOD – ID 26

*H. Moghadam, Sharif Univ., Iran (Islamic Republic Of)*
*M. Mohammadi, Sharif Univ., Iran (Islamic Republic Of)*

In this paper, a newly developed technique is employed for evaluation of cracking strength of infilled frames and compared with some experimental results. The method uses the results of linear finite element analysis and Coulomb failure parameters; friction coefficient and cohesion of mortar joints. The method can either take into account the effect of reinforcement in the cracking strength. Moreover some experimental tests have been performed to validate the proposed method and it was shown that the method can estimate the cracking strength of infilled frames accurately. Two different frames were used in experimental tests which were filled with masonry or concrete infills. The frames are scaled models of the lowest storey of respectively tall buildings and four to five storey buildings. The first one has simple connections of beam to column and the second has rigid connections.

Keywords: Masonry, infill, cracking strength, finite element, experimental tests

### EFFECT OF MASONRY INFILL WALLS ON THE LATERAL BEHAVIOR OF BUILDINGS – ID 494

*A. Ugurhan, Middle East Technical University, Turkey*
*Y. Ahmet, Middle East Technical University, Turkey*
*O. Mehmet Selim, MNG Construction, Turkey*

In most of the reinforced concrete buildings, hollow masonry infill walls are used as non-structural partition walls. Since they are used as a non-structural member, during design stage, their contribution to overall building behavior is not considered. Observations made after major eartquakes in Turkey revealed that these non-structural elements had beneficial effects on the lateral capacity of the building. In this study, the contribuiton of hollow masonry infill walls to the lateral behavior of reinforced concrete buildings is investigated. For this purpose, three and six story symmetric buildings are modeled as bare and infilled frames. Parameters that are investigated are column area, infill wall area, distribution of masonry infill walls throughout the story. To determine the effect of each parameter, global drift ratios are computed and compared.

### RESIDUAL SEISMIC PERFORMANCE OF RC FRAMES WITH UNREINFORCED BLOCK WALL BASED ON CRACK WIDTHS – ID 748

*H. Choi, The University of Tokyo, Japan*
*Y. Nakano, The University of Tokyo, Japan*
*N. Takahashi, The University of Tokyo, Japan*

After an earthquake, the major concerns to damaged buildings are their safety/risk to aftershocks, quantitative damage assessment to evaluate their residual seismic capacity and to identify necessary actions on the damaged buildings. Post-event damage evaluation is therefore essential for quick recovery of damaged community as well as pre-event seismic evaluation and strengthening of vulnerable buildings. Few investigations on masonry walls, however, have been made to quantitatively identify their damage level and criteria to judge necessary actions for their continued use, repair and rehabilitation. In this study, concrete block (CB) infilled reinforced concrete frames for school buildings in Korea, where CB walls are typically unreinforced, are experimentally investigated to develop pre- and post-earthquake seismic evaluation method. In the tests, full-scale, one-bay, single-story specimens having different axial loads in columns and different opening configurations in walls are tested under cyclic loading, and the contribution of CB walls to overall behaviors and crack patterns and widths in walls and frames which may be of great significance for post-event assessment are carefully observed. In this paper, the simplified model to estimate residual deformation from residual crack width in columns and CB walls is proposed, and the relationship between seismic capacity reduction factor and residual crack width (or damage level) is discussed.

## AN INVESTIGATION ON DUCTILITY OF RC FRAME IN FILLED WITH UN-REINFORCED MASONRY WALL SUBJECTED TO CYCLIC LOADING – ID 767

*M. Z. Kabir, AmirKAbir University, Iran (Islamic Republic Of)*
*R. Shahmoradi, AmirKAbir University, Iran (Islamic Republic Of)*

Un-reinforced masonry walls (URM) are widely used in developing country in buildings due to short time and low cost of construction. In Middle East, URM walls are used as both bearing and non-load bearing structural elements. The second usage is concerned with using them as infill in steel and reinforced concrete (RC) framed buildings. However, experiences from the past earthquakes obviously show that stiffness, ductility and other characteristics of these frames have been dramatically changed after adding of such infill. In order to study the effect of URM infill in a RC frame two bare frames are constructed with same geometry, using similar materials. Then, one of them is in filled using conventional brick and mortal without any additional reinforcement. The approach of quasi-static cyclic loading is employed using horizontal actuators to specimens. Out of plane movements is prohibited using lateral support. Displacements in vertical and horizontal are measured by LVDT equipments. The failure mechanism of both specimens is described in details. The evaluation of strength and stiffness degradation of systems is presented based on envelope force-displacement curve of actual specimen under cyclic loads. Results of the current study are shown in the form of ductility factors, hysteresis loops and load-displacement envelope curves. During the test, infill and frame are performed separately. Primarily, there is an increased stiffness due to infill, however, after some diagonal cracks, the wall looses its stiffness, as a result, the load carrying capacity of combined system is considerable declined, and finally the envelope curve of the system reaches to the location where the maximum point of load-deflection curve for bare frame is obtained.

## SEISMIC PERFORMANCE OF AAC INFILLED RC FRAMES – ID 1070

*A. Penna, EUCENTRE, Italy*
*F. Dacarro, EUCENTRE, Italy*
*G. M. Calvi, EUCENTRE, Italy*

Due to their excellent regularity, lightness and insulation properties, autoclaved aerated concrete masonry blocks are widely used in constructions, both for structural and non-structural elements: in spite of a general lack of knowledge about their seismic performance, they are very common even in seismic areas, such as Italy and other European countries. A complete set of experimental activities has been carried out at EUCENTRE and University of Pavia Laboratories in order to assess the seismic capacity of AAC masonry infilled r.c. frames: tests on materials, blocks, small sub-assemblages and wallets have been performed preliminarily. Full scale tests of one-storey single-bay infilled r.c. frames (designed according to EC8) have been performed: several reinforcement solutions for the infill masonry have been tested and compared both for cyclic quasi-static in-plane response and out-of-plane behaviour of in-plane damaged infill walls. Experimental results show interesting applications for AAC masonry for infill panels: high deformability and low weight of the material lead to obtain different performance in comparison with stronger masonry typologies, both regarding the panel damage and the interaction with the r.c. frame. The different reinforcement solutions have been compared in terms of expected seismic response (deformation capacity, energy dissipation) and final damage pattern and some conclusions have been derived from the observed performances. Numerical simulations of the experimental response allow to extend the results obtained in the performed tests to assess whole building seismic performance.

## NUMERICAL MODELS FOR SIMULATION OF THE SEISMIC RESPONSE OF RC STRUCTURES – ID 1082

*H. Rodrigues, University of Aveiro, Portugal*
*A. Costa, University of Aveiro, Portugal*
*H. Varum, University of Aveiro, Portugal*

Seismic analysis of RC structures requires realistic and simple analytical models. In this paper are presented two models proposed and implemented in the program PORANL, to represent the RC buildings behaviour under earthquake loading. The first model represents the influence of infill walls in the global building response, and the second model represents the non-linear shear behaviour of RC elements. The masonry infill walls are commonly used as non-structural components. It is highly recognized that the response of RC buildings to earthquake loads can be substantially affected by the influence of infill walls. It is presented an improved numerical model for the masonry infill walls. The proposed non-linear model is an upgrade of the commonly used equivalent bi-diagonal compression strut model. The response of RC elements to earthquake loads can be controlled by bending or shear behaviour, depending on the geometrical characteristics of the elements. The original version of the PORANL program was able to represent the non-linear bending behaviour. To represent the shear behaviour, in elements where the shear is not negligible, it was developed and implemented in the PORANL a non-linear model. Finally, in this paper are presented and discussed the results of a series of calibration analyses based on tests on full-scale specimens.

## IS ADDING HIGH STRENGTH INFILL WALLS TO THE NON DUCTILE RC FRAMES AN EFFECTIVE RETROFITTING TECHNIQUE? – ID 1179

*E. Yuksel, Istanbul Technical University, Turkey*
*C. Nur, Istanbul Technical University, Turkey*

Masonry infills have usually been used in building type structures for architectural reasons. They have been normally considered as non-structural elements and their presence has been ignored by engineers. The performance of the structure can be greatly improved by the increase of strength arising from the masonry infills. The increase in strength also accompanies the increase of the initial stiffness of the structure which may results increasing of the inertia forces. Due to existence of infill walls, it is dissipated considerable amount of input energy.

The main objective of this study is to investigate the effectiveness of adding high strength infill walls to the RC frames to upgrade their earthquake performance. For this purpose, a 3-bay and 5-storey reinforced concrete frame that represents existing non ductile RC frame type structures in Turkey is analyzed parametrically. The performance of the structure for different strengths of infill walls is assessed using nonlinear time-history analysis. The IDARC2D two-dimensional inelastic finite element program is chosen to perform these analyses.

The results of these analyses will be compared to evaluate the effect of infill strength on the response of non ductile RC frames and the effectiveness of high strength infill walls for retrofitting of RC frames will be criticized.

## RETROFITTING OF REINFORCED CONCRETE BUILDINGS USING MASONRY INFILL WALLS – ID 1374

*S. Nishikawa, Cabinet Office Disaster Management, Japan*
*A. Goyal, I.I.T. Bombay, India*

The collapse of a number of low-strength reinforced concrete (RC) buildings having soft-storey at the ground floor during recent earthquakes is definitely a matter of concern for the construction industry. Most of these buildings had RC moment resisting frame resting on shallow isolated footings, having un-reinforced brick infill panels only above the ground floor level resulting in a soft-storey at the ground floor. Most of these buildings were designed only for gravity loads and were deficient in lateral load resisting capacity and ductility capacity factor. In this paper, it has been demonstrated through analysis of a typical four-storey building that addition of properly designed new masonry infill walls in soft storey, and strengthening of infill walls at other storeys provides the simplest and cost-effective alternative for retrofitting of such buildings. For the example building, extensive non-destructive

tests were conduced to establish material properties. The properties of infill walls used in mathematical model were assessed based on laboratory test results. The numerical results are presented for a real building being retrofitted using infill walls to show that (1) infill-walls protect the columns by sharing lateral forces, (2) infill-walls absorb significant amount of energy through damage, and infill-walls provide an alternate gravity load carrying system. The ultimate collapse of retrofitted building is preceded by large drift. It has been demonstrated in the paper that repeated analyses are necessary to find the optimum locations of new infill walls, and detailed engineering is required for proper load transfer.

### 3D NONLINEAR RESPONSE SIMULATIONS OF BAM TELEPHONE CENTER RC BUILDING TO THE 2003 BAM EARTHQUAKE – ID 1528

*M. Hooshmandzadeh, Islamic Azad University of Shushtar Branch, Iran (Islamic Republic Of)*

Bam telephone center building, with a nonsymmetrical reinforced concrete moment resisting frame structure, is located about 1.5 km northeast of the 2003 Bam earthquake strong motion station. Based on the post-earthquake damage assessment results, almost no nonlinear residual deformations or cracks were observed on the structural elements of the building. However, assuming the designed base shear coefficient of the structure, nonlinear responses were expected for the building due to the earthquake. Hence, in order to obtain an analytical answer for the linear performance of the building, three- dimensional nonlinear time history analyses were carried out for the building, subjected to the North-South and East-West recorded strong motions. The response simulations were implemented in different categories for the bare frame and the infilled frame. An approach was developed for modeling masonry infill walls with or without openings. The results of the analyses were compared with the observed damages and residual cracks on the masonry infill walls. Reasonable correlations were obtained between the analytical results and the observed ones. It might be concluded that existence of the masonry infill walls is the main reason for the linear responses of Bam telephone center building, during the earthquake.

### A THREE-STRUT MODEL REFINEMENT FOR INFILLED FRAME ANALYSIS – ID 1609

*S. Biondi, University of Chieti-Pescara, Italy*
*E. Candigliota, University of Chieti-Pescara, Italy*
*C. Nuti, Dis Structure Department Third University of Rome, Italy*

Experimental results on specimens and behaviour of real structures subject to earthquake show clearly that the interaction between r.c. frames and infilling panels can determine stress concentration and fragile failure in the structure. Shear stress concentration can happen in columns not only for particular geometric dispositions but also for frame to infilling panel interaction. Such phenomena have to be considered in a non linear analysis of the structure. Otherwise if the simplified model of equivalent strut is used, it is noted a clear discordance between the experimental and theoretical results with respect to stress distribution in r.c. elements, particularly in lateral columns. A simple scheme of an equivalent three diagonal struts instead of the traditional single one is presented. It seems to be able to give good levels of accuracy in non linear field. The main aspects in the model are position (that influences the stress level in r.c. elements) and dimension (that influences the global system stiffness) of the equivalent struts. In order to validate this model, an experimental test program at CEA Structural Laboratory is been carried out while static tests are in progress at Authors laboratories. Numerical analyses on multi-storey and multi-bay frames are carrying out. Criteria to evaluate strut mechanical characteristics from material orthotropic strength parameter as well as to establish the position and dimensions of the struts in the frame are given. Using the proposed three-strut model a better definition of shear distribution in r.c. frame elements can be obtained in comparison to single strut model. Particularly if the peak strength level for infilled frame is assumed as serviceability limit state, in this range the single strut model could overestimate structural capacity and shear values in columns obtained with three-strut model are more realistic than single strut model ones.

## STS E10: By How Much Does the Natural Frequency of Structures Decrease During Seismic Response ?

Level-1

### LOW AMPLITUDE VERSUS HIGH AMPLITUDE MOTIONS IN FUNDAMENTAL PERIOD ASSESSMENT OF BUILDINGS – ID 884

*A. Jalali, University of Tabriz, Iran (Islamic Republic Of)*
*M. Razeghi, University of Tabriz, Iran (Islamic Republic Of)*

The Iranian code has adopted the period formulas contained in the 1997 UBC (uniform Building Code, 1997) which were derived largely based on periods of buildings measured from their motions recorded during the 1971 San Fernando earthquake. Because of drastic differences between buildings in Iran and United States of America in terms of material and type of buildings and also workmanship, suitability of such empirical formulas is questionable. The objective of this investigation is to develop improved empirical formulas to estimate fundamental vibration period of reinforced-concrete(R/C), steel moment-resisting frame(MRF) and dual system buildings for use in equivalent lateral force analysis specified in building codes, which is developed based on our own building data in Iran. In this research the results of ambient vibration measurements on 30 reinforced concrete buildings and 30 steel structures located at Tehran and Tabriz have been presented. Ambient vibration measurements have been conducted on buildings designed according to Iranian code, and the results of such measurements have been compared with code formulas. The results show that in all cases the fundamental periods predicted from ambient vibration measurements fall below those obtained from empirical formulas of the code, as if the code predicted periods act as upper limit for test results. In order to find a reasonable relation between fundamental periods obtained from low and high amplitude motions, extensive study of recorded ground motions on different buildings during earthquakes have been conducted. We have used records from main shocks, pre-shocks and after-shocks of certain earthquakes. In selecting the records, we excluded the records that have driven the buildings into their nonlinear behavior. Amplitude dependency of vibration properties of buildings has been discussed, and recommendations for adopting new empirical formulas based on the results of ambient vibration tests have been made for Iranian code.

### DYNAMIC AUSCULTATION OF BUILDINGS AND SEISMIC INTEGRITY THRESHOLD ASSESSMENT – ID 1002

*S. Hans, ENTPE, France*
*C. Boutin, ENTPE, France*
*E. Ibraim, University Walk, UK*
*P. Roussillon, BRGM, France*

Recent results of in situ measurements and their interest for a seismic assessment of existing buildings are presented and analyzed. The methodology is exposed on three steps. First an experimental program was performed in order to justify the use of vibration data collected in situ for identifying the actual dynamic behaviour of usual intact buildings built according to the common practise. The response to ambient vibrations, harmonic excitation and shock loading is recorded on intact buildings but also after their structure or their vicinity was modified. Taking advantage of the demolition, the tests enable to determine the actual influence of the light work elements, full precast facade panels, bearing masonry walls, and the presence of neighbouring joined buildings. These experiments realized on seven real buildings show that

information gathered from ambient measurements provide reliable and efficient data of real interest for a clear understanding of the actual building behaviour. Second it is shown that the experimental modal characteristics obtained on regular concrete buildings are described successfully by suited classical or uncommon continuous beam modelling consistent with the internal structure. In a given direction of motion the key identification parameter of the relevant modelling is the frequency distribution of the two (or three) first eigenfrequencies. Third, the advantage of integrating these previous developments in the vulnerability assessment is presented and discussed. Choosing the maximum tensile strain of concrete as damage criterion for key structural elements, a maximum level of the ground acceleration (in regulation meaning, as PS92) can be determined. This so-called Seismic Integrity Threshold is directly related to the onset of structural damages. This new approach is illustrated by using the in situ records of one of studied buildings. This work underlines the advantages of using ambient vibrations survey for the vulnerability assessment of existing buildings.

## DYNAMIC CHARACTERISTICS OF AN 8-STOREY BUILDING ESTIMATED FROM STRONG MOTION RECORDS – ID 1005

*T. Kashima, Building Research Institute, Japan*

Understanding of dynamic characteristics of building structures is a key issue in the seismic design technology. From this point of view, Building Research Institute (BRI), Japan, has been operating the strong motion network for buildings since 1957. The BRI annex building is one of the stations of the BRI strong motion network and is densely instrumented with 22 accelerometers. In this paper, variation of dynamic characteristics of the annex building is discussed through analyses using strong motion records. Decreasing of fundamental natural frequencies of the annex building with the passage of time is recognized from the optimizing analysis of 158 strong motion records using a single-degree-of-freedom system. 16 strong motion records with relatively big displacements are selected in order to examine such phenomena in detail. The Evolution Strategies (ES) algorithm is applied to the optimizing analysis using a multi-storey sway-rocking model. The ES is a powerful problem-solving tool based on natural evolution. Building stiffness, rocking stiffness, swaying stiffness and building modal damping ratio are estimated for each strong motion record using the ES algorithm. The rocking stiffness, the swaying stiffness and the modal damping ratio of the building show stable behavior with the passage of time. Consequently, it is confirmed that the decreasing of the natural frequencies is caused by the softening of the building stiffness.

## SIMPLIFIED EQUATIONS FOR ESTIMATION OF PERIOD OF VIBRATION OF EXISTING BUILDINGS – ID 1122

*H. Crowley, ROSE School, Italy*
*R. Pinho, University of Pavia, Italy*

Currently, seismic design of new European buildings follows a force-based approach, whilst the assessment of existing buildings is moving towards a displacement-based philosophy. In force-based design, conservative estimates of the period of vibration should be produced such that the base shear force will be conservatively predicted from an acceleration spectrum, and thus the use of gross section (un-cracked) stiffness is perhaps acceptable. Nevertheless, the formula given in the current version of EC8 has been developed using Californian building stock based on the assumptions that the base shear is proportional to 1/T∧2/3 and the deformations are controlled by the drift limit-state. This formula should ideally be calibrated to European building characteristics and EC8 design spectra properties. For assessment of buildings, the use of the un-cracked stiffness in the determination of the period is certainly inappropriate considering cracking of critical elements such as beams generally occurs under gravity loading alone. However, if cracking is not found to have occurred before the design seismic level of excitation (considered unlikely as this level of excitation would with all probability have been preceded by a number of lower intensity events), it will occur early on in the response to excitation and thereafter the stiffness will reduce rapidly leading to the loss of the tension stiffening effect of the concrete. Thus, the reliable stiffness of the members of an existing RC frame can only be confidently taken as the yield stiffness. The un-cracked and yield period of new and existing European reinforced concrete buildings of varying height both with and without infill panels is analytically calculated herein using both eigenvalue and pushover analyses. The results are compared with the current European code-based formula (i.e. T1=CtH∧3/4) and proposals to update this equation for design and assessment, respectively, are presented.

## MONITORING THE DYNAMICS OF A CONCRETE BUILDING ENDURING EARTHQUAKE AND WIND EXCITATION – ID 1207

*J. Snæbjornsson, University of Icland, Iceland*
*O. Thorarinsson, University of Iceland, Iceland*
*A. Carr, University of Canterbury, New Zealand*
*R. Sigbjornsson, University of Iceland, Iceland*

Earthquake and wind induced acceleration data has been systematically collected in a 14-story reinforced cast-in-place concrete building over period of 14 years. The building has been subjected to repeated earthquake and wind induced excitation. The earthquake database for the building presently contains records from over 100 events ranging from magnitude $2\frac{1}{2}$ to $6\frac{1}{2}$ with acceleration amplitudes of up to 22% g. The wind data catalogue is larger but generally contains lower amplitude data. The geometry of the building is rather complex, as the floor plans vary, changing vertically. The instrumentation is located at three levels: the basement, the 8th floor and the 14th floor. The recorded acceleration data is used for system identification of the building. The aim is, to use system identification techniques and the available recordings to assess the basic dynamic properties of the building, i.e. the natural frequencies and critical damping ratios for the main modes of vibration. Furthermore, to examine the variability of the system parameters and their dependence on the excitation conditions. Finally, to check if any changes in structural behaviour can be observed throughout the observation period. The results serve both as a baseline for damage identification as well as calibration data for further structural modelling of the buildings. Changes in the system parameters are observed, which apparently depend both on time as well as excitation level. A slow increase in flexibility is observed during the whole observation period, in addition to an instantaneous decrease in natural frequencies after each earthquake. The pronounced decrease in natural frequencies after the bigger earthquakes is followed by a recovery period where the natural frequencies increase slowly and tend towards the 'initial' ones. The 'instantaneous' decrease in natural frequencies is accompanied by increase in corresponding critical damping ratios, which support the interpretation of weak non-linear behaviour.

## IN SITU EXPERIMENT AND MODELLING OF RC-STRUCTURE USING AMBIENT VIBRATION AND TIMOSHENKO BEAM – ID 1246

*C. Michel, LGIT, France*
*S. Hans, ENTPE, France*
*P. Gueguen, LGIT, France*
*C. Boutin, ENTPE, France*

Recently, several experiments were reported using ambient vibration surveys in buildings to estimate the modal parameters of buildings. Their modal properties are full of relevant information concerning its dynamic behaviour in its elastic domain. The main scope of this paper is to determine relevant, though simple, beam modelling whose validity could be easily checked with experimental data. In this study, we recorded ambient vibrations in the Ile Verte 28 stories building of Grenoble (France). This building has been selected because of the vertical structural homogeneity (28 identical stories). First, a set of recordings was done using a 18 channels digital acquisition system (CityShark) connected to 6 3C Lennartz 5s sensors. We used the Frequency Domain Decomposition (FDD) technique to extract the modal parameters of this building. Second,

it is shown in the following that the experimental quasi-elastic behaviour of such structure can be reduced to the behaviour of a vertical continuous Timoshenko beam. A parametric study of this beam shows that a bijective relation exists between the beam parameters and its eigenfrequencies distribution. Consequently, the Timoshenko beam parameters can be estimated from the experimental sequence of eigenfrequencies. Having the beam parameters calibrated by the in situ data, the reliability of the modelling is checked by complementary comparisons. For this purpose, the mode shapes and eigenfrequencies of higher modes are calculated and compared to the experimental data. A very good agreement is also obtained. In addition, the beam model integrates in a very synthetic way the essential parameters of the dynamic behaviour.

## REAL-TIME STRUCTURAL HEALTH MONITORING INCORPORATING SOIL STRUCTURE INTERACTION EFFECTS – ID 1271

*S. Soyoz, UC Irvine, United States*
*M. Q. Feng, UC Irvine, United States*
*E. Safak, USGS, United States*

Modal parameters are often used for the purpose of structural health monitoring (SHM) and damage detection. However, environmental conditions and, more importantly, soil-structure interaction (SSI) can also cause changes in modal parameters. So a rational way is to construct a database of the modal parameters under different environmental conditions and earthquake excitations, so that their effect can be excluded when evaluating structural damage.

The authors have instrumented the CalIT2 building, a four-story reinforced concrete structure, located on the UC Irvine Campus with 43 accelerometers. What makes this building special is that these sensors are not only installed on the building structure, but also in the free field, and deep onto the rock layer of the soil foundation, making it possible to examine the SSI.

Starting from November, 2004 when this building was new and unoccupied, ambient vibration of the building has been regularly measured and the dynamic characteristics of the structure identified to develop a database. Within one year, two moderate earthquakes were also recorded. It was observed that the modal parameters obtained during the earthquake excitations differ from those obtained under ambient vibrations. The change was found to be mainly due to the SSI. So far, the SSI has not been taken into consideration in the current structural health monitoring research, which may result in erroneous results. The discovery made in this research will contribute to the development of a realistic framework for health monitoring of real-life civil engineering structures by incorporating SSI with monitoring.

Real time data and current status regarding the SHM of Cal-IT2 can be found on: http://mfeng.eng.uci.edu/Maria_Feng/Research_activities/health_monitoring/ waveform2.html

## A STUDY ON THE CHARACTERISTICS OF EARTHQUAKE GROUND MOTION ON BUILDINGS BASED ON STRONG-MOTION OBSERVATIONS – ID 1367

*S. Koyama, Building Research Institute, Japan*

In order to proceed with the rationalization of the seismic design technology, it is necessary to understand the characteristics of earthquake ground motions and the earthquake response behavior of building during earthquake. Building Research Institute has installed strong motion observation instruments for 50 years. The prototype measuring system usually consists of both on the top and in the foundation of the building and adjacent ground surface. In several buildings, additional sensor with prototype system are conducted to get much more information about the earthquake response behavior of building during earthquake. Especially, in case of annex building of BRI, the amplification process by the surface layers of ground and the three-dimensional behavior of the building are recorded using 66 components by 22 tri-axial sensors placed in and around the building simultaneously. The microtremors observations are also conducted to get the resonance characteristics of building and soil structure interaction in small amplitude. On Oct. 23, 2004, the Mid Niigata Prefecture Earthquake was occurred. At two observation sites by JMA and NIED in Ojiya city Niigata prefecture, the excessive acceleration records were obtained by main shock and principal aftershocks. The aftershocks observation using prototype measuring system was conducted at two reinforced concrete buildings adjacent to these JMA and NIED' observation sites. Through these several kinds of observations, the decrease of amplitude at foundation level to adjacent ground surface is recognized. That could be considered the effects of kinematic soil structure interaction.

## VARIATIONS OF APPARENT BUILDING FREQUENCIES - LESSONS FROM FULL-SCALE EARTHQUAKE OBSERVATIONS – ID 1547

*M. Todorovska, University of Southern California, United States*
*M. Trifunac, University of Southern California, United States*
*T. Y. Hao, University of Southern California, United States*

Results are presented on the variations of the system frequency of more than 20 instrumented buildings in the Los Angeles area, exposed to multiple earthquake shaking, both weak and strong. All buildings recorded the 1994 Northridge earthquake (MS= 6.7) and some of its aftershocks, and many also the 1971 San Fernando earthquake (MS = 6.6), both of which caused extensive damage in the metropolitan area. For each event, the instantaneous system frequency was estimated and plotted versus time and versus the instantaneous amplitude of response. This made it possible to study its variations during a particular earthquake, and from one earthquake to another. The system frequencies observed during ambient vibrations, available for some of the buildings, were higher than those observed during strong shaking. The system frequencies were the lowest during the 1994 Northridge and 1971 San Fernando earthquakes, suggesting system softening during strong shaking, and increased during the aftershocks, suggesting system recovery. The observed temporary changes were typically up to about 20%. This "recovery" was interpreted to be due to dynamic compaction of the soil during the (weak) aftershock shaking. The temporary changes of the building apparent frequencies were interpreted to be mostly due to changes in the soil.

Results are also presented on the instantaneous system frequency in an instrumented building severely damaged by an earthquake and later demolished. The initial observed decreases of about 28% for NS and 24% for EW motions, are not believed to be due to damage, based on analysis of drifts and detected novelties in the recorded response using wavelets. The subsequent decreases, of about 44% for NS and 21% for EW motions, are attributed to damage. Near the end of shaking, increases of about 35% for the NS and 36% for EW motions were observed, suggesting system hardening.

## FREQUENCY AND DAMPING SHIFT DUE TO A DAMAGING EARTHQUAKE: THE CASE OF MOLISE (2002) ITALY – ID 1848

*M. Mucciarelli, DiSGG - Università della Basilicata, Italy*
*M. Dolce, DiSGG - Università della Basilicata, Italy*
*M. R. Gallipoli, DiSGG - Università della Basilicata, Italy*
*A. Masi, DiSGG - Università della Basilicata, Italy*
*F. C. Ponzo, DiSGG - Università della Basilicata, Italy*
*M. Vona, DiSGG - Università della Basilicata, Italy*

During the 2002 seismic sequence in Molise (Italy), the town of Bonefro suffered moderate damage (I= VII MCS ) except for two reinforced concrete buildings. These buildings are located on soft sediments, close to each other and very similar in design and construction. The main difference is the height: the most damaged one (European Macroseismic Scale damage 4) has four stories, whereas the less damaged (EMS damage 2) has three stories. The M 5.4 shock on 31 October damaged both of them. The second shock on 1 November (M 5.3) increased the damage on the four-story building, just while a 5-min. seismic recording was taken. We analysed the recorded data using four different techniques: short-time Fourier transform (STFT), wavelet transform (WT), horizontal-to vertical spectral ratio (HVSR), and horizontal-to-vertical moving window ratio (HVMWR). All the

results agree upon the estimate of the main building frequency before the second shock and upon the shift of frequency due to damage. All the fundamental frequencies (pre-, during-, and post-damage) are in the range 2.5–1.25 Hz. During the quake there is a reduction of frequency of about 40%, partly restored after the coda. The damping increases of a factor 2.5 during the damaging phase. In the framework of an international benchmark project (BOB-Code) we performed numerical analyses to try reproducing the observed building behaviour. The global properties and their variation were matched by a pushover analysis, while for modeling the onset and localisation of damage it was necessary to make some assumption concerning the distribution of concrete mechanical properties.

### CHANGING NATURAL FREQUENCIES IN STRUCTURES : THE CASE OF MILLIKAN LIBRARY – ID 1918

*J. Clinton, ETH, Switzerland*
*T. Heaton, Caltech, United States*
*C. Bradford, Caltech, United States*

The 9 story reinforced concrete Millikan Library building on the campus of Caltech, CA, USA, is one of the most well studied structures in the world. Since its construction in 1967, it has been permanently instrumented, with yearly forced vibration measurements. It has survived (and recorded) numerous relatively strong motions from moderate local events (the 1971 M6.6 San Fernando, 1987 M6.1 Whittier Narrows, 1991 M5.8 Sierra Madre and 1994 M6.7 Northridge events all produced accelerations in excess of 300cm/s/s at the roof). Since 2001, the Southern California Seismic Network has been archiving continuous 20sps triaxial data from the 9th floor. A 36 channel triggered array has been operating since 1998. The structural system has suffered a permanent fall in natural frequency of 22% in the fundamental mode since 1968, caused primarily by the strong motions. During each strong motion event, the natural frequencies temporarily drop by about 20% before recovering most of the lost stiffness. These changes have occurred without any major evidence of structural damage. The continuous data additionally suggests there are measurable changes of the natural frequencies, about 2-5%, at various timescales, apparently in response to changes in weather conditions (clear correlations are observed with temperature, wind and rain), and building usage (such as weekends and evenings. when the elevators are not used frequently, or when library space is given over to office space). The mechanism producing these changes is not known, and may indeed be different for strong motion and ambient vibrations. Potential mechanisms for the temporary and permanent drops during strong shaking include the degradation of non-structural elements in the superstructure; rocking facilitated by horizontal cracks in the inner shear walls at the basement; and non-linear softening or compaction of the soil underneath the building.

### COMPARISON OF PERIODS OF BUILDINGS DUE TO STRONG AND WEAK MOTION – ID 2062

*M. Celebi, U. S. Geological Survey, United States*

Results are presented for the periods of five full-scale buildings instrumented by the U.S. Geological Survey, determined from recorded response to weak (ambient noise or smaller earthquakes), and stronger earthquake shaking. The results show that the building periods can vary significantly as function of the amplitudes of the response, from few percent up to 100%.

### BY HOW MUCH DOES THE NATURAL FREQUENCY OF STRUCTURES DECREASE DURING SEISMIC RESPONSE?- IZIIS EXPERIENCE FROM SHAKING TABLE TEST OF REDUCED SCALE MODEL – ID 2067

*L. Tashkov, Institute of earthquake Engineering-IZIIS, Macedonia*
*L. Krstevska, Institute of earthquake Engineering-IZIIS, Macedonia*

The seismic response of the structure depends on several parameters such as: dynamic properties of the structures (natural frequencies, mode shapes and damping), continuity of the stiffness along the structure, seismic input (frequency content and amplitudes of motion), resonant effect, soil-structure interaction etc. All above-mentioned parameters and/or particular ones, could provoke slight or significant decrease of natural frequency of the structure. This phenomenon could be investigated by making observation on full-scale structure (during earthquake, forced vibration test with different loading force as well as by performing controlled explosion test with different intensity) or by making shaking table test on reduced scale models. IZIIS experience in testing models within the period of 1983-2006, offers many data regarding this phenomenon for both field and laboratory measurements. In this paper, the experience from shaking table test of model of mixed reinforced concrete-masonry building in scale 1/3, as well as of a model of 105 storey RC hotel building in scale 1/40 will be presented.

## STS E11: Petrochemical Facilities and Large LNG Storage Tanks
Level-1

### SEISMIC RETROFIT OF 153 GAS STATIONS IN CITY OF TEHRAN – ID 114

*F. Nateghielahi, AZAD U. SOUTH, Iran (Islamic Republic Of)*
*A. Foroughi, ERC-TEHRAN, Iran (Islamic Republic Of)*

Iran is a country with high seismicity while Tehran, the capital city is located on the highest seismic zone of the nation and also is home to more than 10 million people. There exist 153 gas stations throughout the metropolitan which are constructed to old building codes with little or no attention to seismic considerations. In this study which was supported by the national oil company, first a site investigation of each station was carried out creating a general seismic hazard map. A detailed review of the existing drawings and creating AS Built drawings by opening different sections of the stations and contrasting against the original drawings were then established. After completing the as built drawings, a series of qualititative and quantitative investigations based on structural and finite element analysis was performed resulting in weak link identifications for two performance levels namely; life safety and immidiate use. Based on analytical investigations, deem-to-comply strengthening details and drawings were constructed. This procedure was repeated for the main building, shed structure, piping and tanks, pumps and mechanical units. This paper will provide details in regards to the analytical investigations, findings and retrofiting techniques which were used to achieve the goals of the project.

### QUALITATIVE AND QUANTITATIVE SEISMIC EVALUATION OF R/C STRUCTURES IN PETROCHEMICAL PLANTS – ID 123

*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*
*A. Rezaie, ERC-Tehran, Iran (Islamic Republic Of)*

In this paper the seismic evaluation of reinforced concrete structures in petrochemical facilities under sever conditions such as high pressure, high temperature and corrosive environment is studied. These structures were designed and constructed during 1976-78. The evaluation procedure is basically performed in two phases namely; a) qualitative and b) quantitative methods. In the qualitative evaluation, all possible documentations including drawings, specifications, structural calculations, new additions and test results were studied. Collected data then was summarized in an evaluation checklist. When the needed requirements did not meet the specified entries, more detailed and quantitative analysis were performed and utilized in this study. Quantitative and numerical study was performed using finite element modeling under sever loading combinations. Based on the results of this evaluation, some important RC structures in this plant were highly

vulnerable to seismic forces which required immediate attention. The methodology used and results obtained can be generalized and adapted for similar facilities. This paper will present details, procedure and conclusions obtained.

### EVALUATION OF SEISMIC VULNERABILITY OF EXISTING UN-ANCHORED TANKS USING NUMERICAL ANALYSIS – ID 325

*M. Seyed Razzaghi, IIEES, Iran (Islamic Republic Of)*
*S. Eshghi, IIEES, Iraq*

Damage to on-grade cylindrical liquid storage tanks due to the past earthquakes such as Izmit, Turkey earthquake (1999) showed that these structures are seismically vulnerable. The dynamic behavior of cylindrical steel tanks can be affected by several parameters such as height-to-diameter (H/D) ratio, the elevation of liquid table, and the specifications of the ground motion. The base anchorage has a great role in seismic response of on-ground cylindrical tanks. Many of the un-anchored tanks may experience base uplift during the major seismic events; meanwhile the response of the tank may strongly affected by the base uplift. The objective of this study is to investigate the effect of the aspect ratio and the volume of contained liquid on seismic vulnerability of un-anchored cylindrical liquid storage tanks. In this study numerical analysis carried out to investigate the nonlinear behavior of the existing tanks of various aspect ratios (H/D=0.4, 0.5, 0.6) and various liquid table levels (20%, 50%, 60%, 80% full) due to the strong ground motions and the base uplift, axial compression and hoop stresses were estimated for each case and the results were compared to the code provisions. The results of this study shows that the base uplift and the axial compression stress and the hoop stresses of the wall of un-anchored tanks (especially in taller tanks) may be strongly affected by variation of the volume of the contained liquid. Thus the level of liquid table has a great effect on seismic vulnerability of un-anchored storage tanks.

### SEISMIC ASSESSMENT OF STEEL STRUCTURES IN A PETROCHEMICAL PLANT – ID 335

*A. Rezaei Tabrizi, ERC, Iran (Islamic Republic Of)*
*F. Nateghi-A., IIEES, Iran (Islamic Republic Of)*

Importance of industrial facilities and their vulnerability to earthquake motions have been shown in just about any earthquake throughout the world. Iran being a major oil producing country with substantial amount of investments placed on the production, storage, processing and the transportation of this natural produce, from one side, and the high seismicity of Iran from other side, has made the seismic vulnerability assessment of these facilities a priority number one for the government officials. In doing so, a major project was lunched in order to investigate the current status of existing structure in Shiraz Petrochemical facilities. This paper is to present the methodology used and results obtained for this particular steel structures which indeed are not only vulnerable to earthquakes but also have been exposed to sever corrosion and high temperature environment. Screening was performed using ATC-14 and analysis was considered by utilizing the ASCE standards as well as Iranian-2800 seismic building code. Site investigation and seismic hazard study was done for the complex and based on that a 475 return period earthquake was used for the spectral analysis. Demands to capacity ratios were calculated for the members of the structures and the following criteria were used to classify the damage classification. The criteria is; D/C <1.1 safe, 1.1<D/C<1.2 vulnerable and D/C>1.2 very vulnerable. Corrosion on structural steel member was consider by using NDT tests and counted as a reduction in member sizes.

### PARAMETRIC ANALYSES FOR THE SEISMIC ISOLATION OF LNG TANKS – ID 1046

*G. Bergamo, CESI, Italy*
*M. G. Castellano, FIP Industriale, Italy*
*F. Gatti, CESI, Italy*
*V. Rebecchi, CESI, Italy*

This paper describes the results of parametric numerical analyses conducted on a simplified Housner model of two typical Liquefied Natural Gas tanks, of 100,000 and 60,000 cubic meters capacity respectively. The scope of said analyses was to study the structural response of LNG tanks equipped with different types of seismic isolation systems, i.e. high damping rubber bearings, lead rubber bearings, and low damping rubber bearings combined with non-linear fluid viscous dampers. The main variable parameter was elastic or post-elastic stiffness (depending on the type of seismic isolation system considered) which leads to different values for the effective fundamental period. The effective equivalent viscous damping variation ranges from 10 to 40 %. Non-linear time-history analyses were carried out. The seismic input was an accelerogram compatible with EC8-Soil C spectrum, with PGA=0.4g. For high damping rubber bearings, both the equivalent linear and non-linear constitutive models were used so as to compare results and provide guidelines for modelling design. The benefits of seismic isolation with any type of seismic isolation system were amply demonstrated. The study was carried out within the framework of the EC-funded INDEPTH project.

### A COMPARISON STUDY ON SEISMIC PROTECTION SYSTEMS FOR SPHERICAL LIQUID STORAGE TANKS – ID 1136

*J. Drosos, University of Patras, Greece*
*S. Tsinopoulos, University of Patras, Greece*
*D. Karabalis, University of Patras, Greece*

A numerical study on the dynamic behavior of a typical spherical liquid storage tank, equipped with various seismic protection systems, is presented. Five different anti-seismic devices are investigated; nonlinear viscous dampers, buckling restrained braces and friction devices (passive energy dissipation) and lead core and high damping rubber bearings (base isolation). The numerical analysis is performed by means of a detailed finite element model, taking into account the exact geometry of the steel tank, the fluid-structure interaction effects for an arbitrary level of filling, the soil-structure interaction as well as the non-linearities introduced by the dissipative bracing systems. Representative results for base shear forces, vertical displacements of the fluid content and displacements at characteristic locations of the spherical tank are presented and compared to those corresponding to a tank with a conventional bracing system. The research has been performed in the framework of the project INDEPTH (Development of INnovative DEvices for Seismic Protection of PeTrocHemical Facilities), supported by the Environment and Sustainable Development Programme of the European Commission Research Directorate General (Contract EVG1-CT-2002-00065).

### EFFECT OF FILLED LIQUID ON DYNAMIC RESPONSE OF LIQUID STORAGE STRUCTURES SUBJECTED TO EARTHQUAKE LOADING – ID 1358

*P. Bhuvaneshwari, Anna University, India*
*S. Elangovan, Anna University, India*
*P. Chellapandi, Indira Gandhi Centre for Atomic Research, India*

Ground supported liquid storage structures are of different shapes such as rectangular, cylindrical, spherical, conical and with geometry as broad or tall depending on their requirements. The storage structure's dynamic responses are largely affected by the inner filled liquid properties. Earthquake response of liquid storage structures are significantly influenced by the interaction between the inner filled liquid and containers. This phenomenon referred as fluid-structure interaction includes sloshing behavior of filled liquid and dynamic behavior of container. Prior to the study on seismic responses, the containers of different shape and geometry are subjected to free vibration. Theoretical knowledge on free vibration of coupled fluid-structure system is utilized for developing a numerical model to study fluid-structure interaction effects in liquid storage structures, using general purpose code ANSYS. Free vibration analysis results in both structural vibrational modes and

low frequency sloshing modes. The fundamental period of sloshing is far longer compared to that of structure and this assures for decoupling between liquid sloshing modes and structure vibration modes. Since the depth of filled liquid play a significant role in influencing the eigen frequency, depth of filled liquid are varied in steps of 0.25D where 'D' is the depth of the container. The variation in the first mode frequency, maximum sloshing amplitude, maximum structural deformations for different depths of liquid are studied for rectangular, conical and cylindrical containers. After deciding the critical depth of liquid, each container is filled to the critical depth and time history analysis is performed for N-S component of Elcentro earthquake record to track the responses of the structures in time domain. The similar containers in empty condition are subjected to same seismic loading. Comparison of results shows that the filled liquid has enhancing effect on structural responses, namely displacements, stresses, strains, reaction forces and moments.

### SEISMIC RESPONSE OF LARGE CYLINDRICAL TANKS FOR OIL STORAGE WITH FLEXIBLE WALLS – ID 1411

*S. Mukat, IITR, India*
*H. A. Sanchez Sanchez, Instituto Politecnico Nacional, Mexico*
*C. Cortes Salas, Instituto Mexicano del Petroleo, Mexico*

In Mexico, PEMEX manage different terminals of storage of oil in all our country. Therefore, structural integrity of the aboveground storage tanks must be carefully assessed. Also the growing need to satisfy the national oil industry has in the last years required the evaluation and retrofit of the existing structures, in addition to create new oil terminals for distribution and oil products. As a consequence, some storage tanks have been placed in high seismic risk areas. Consequently, this research has focused on the behavior and response, under seismic conditions, of already existing steel storage tanks of large capacity, of 500 and 200 thousands barrels, located in high risk zones. From the revision of analysis and design criteria concerned with thin walls structures, it has been proposed a procedure based on a numeric modeling where the mechanical characteristics of the materials and the real geometrical have been considered. Concerning the real geometrical measures we found that geometrical imperfections in the tank wall do modify stability and response of the same structure. The FEM has been used to carry out such analysis. Numeric analysis have been used in different conditions: empty tanks vibration, full tanks where fluid-structure interaction is considered to the case of flexible walls, real and synthetic seismic records of subduction originated in the Mexican Pacific Ocean as well as normal failures, have been used. These records are used as seismic excitation at the base of the structures in order to take into account the pressure distribution of the liquid. Research results have been compared to recommended codes and regulations such as API-650, API-653, and to the seismic action to which the structures are undertaken to. Finally, the results will be used to determine new lines to design and revision the steel storage tanks in the regulations environment in our country.

## SC-A 1: Archaeological and Historical Studies on the Earthquakes of the Past Centuries

Level 2

### THE M=6.2 EARTHQUAKE OF JANUARY 13 (1804) IN MOTRIL (SPAIN) – ID 91

*A. Posadas, Applied Physics, Spain*
*F. Vidal, Andalusian Institute of Geophysics, Spain*
*M. Navarro, Applied Physics, Spain*

The area under study is situated in the south part of the Betic Cordilleras (Southern Spain), just in the border of Granada Basin. The seismogenetic areas are concentrated in three fracture systems having N10-30E, N30-60W and N70-100E directions. These faults has a high activity microearthquakes with hypocenters shallower than 20 km. Southern Spain is the region with the highest hazard level in Spain due to it is located in the interaction zone between the Euroasian and African plates. Fortunately, the majority of earthquake magnitudes are less than 5.0. However, catastrophic earthquakes occurred in the past with intensities (MSK scale) ranging from IX to X: Vera earthquakes (1406 and 1518) caused lots of damages in this town; Almería big earthquake (1522), destroyed buildings like the Alcazaba (Arab castle built about 955 bc. with more than 43000 m2 of extension) and the cathedral. The Andalusian 1884 Earthquake was the most important event in this area and serious damages were found in cities far away the epicenter zone. One of the most important earthquakes of century XIX was the one of the 13 of January of 1804 located in the coastal city of Motril; this earthquake so has not been studied as others due to the proximity in time with other happened the 25 of August of the same year in the near locality of Dalías killing 300 people while the earthquake from Motril only caused two dead ones according to consists in the analyzed documentation. It has compiled abundant historical information of the time and later times including acts of the city council, regional and national periodic magazines and newspapers and then, an intensity maps has been constructed for the zone of damages. In addition, the magnitude of the earthquake has been considered from the analysis of intensities.

### THE 1518 VERA (SPAIN) EARTHQUAKE – ID 917

*F. Vidal, Andalusian Institute of Geophysics, Spain*
*M. Espinar, Andalusian Institute of Geophysics, Spain*
*E. Ocaña, Andalusian Institute of Geophysics, Spain*

The November 9, 1518 Vera (Southeastern Spain) earthquake destroyed completely the town of Vera, that had to be rebuilt in a nearby site. The 1518 and 1406 Vera earthquakes (the second one was less destructive) are analysed using 41 historical documents obtained from the Archives of Vera, Almeria, La Alhambra, the National Library of Madrid and the Archive of Simancas. This analysis reveals important aspects of town and village urbanism, material characteristics and construction techniques of walls, churches, houses, cisterns, etc. All this information is useful to analyze vulnerability and seismic damage in buildings. The most affected village was Vera, which was devastated, including the most resistant buildings, (as the fortress and the city walls). Mojacar collapsed partially and the others buildings were seriously damaged. Its fortress had similar damage that Vera one, where big failures and partial collapses were located in more than forty places on it. Similar damage than Vera occurred in the town of Cuevas. Furthermore, six vigilance towers in the coast were pulled down, like the one in Garrucha. The estimated EMS intensity values are: IX degree (due to topographical effects) in Vera, VIII degree in Mojacar, Garrucha, and Cuevas. Damages related to other villages reported in the historical documents ares less accurate to assess their intensities. Number of deaths was quite large: 150 in Vera (more than 20%) and 15 in Mojacar. In Vera practically all inhabitants were injured (except for 6 or 7 people) and most of them in Mojacar

### HISTORICAL EARTHQUAKES DAMAGE AT SS. SALVATORE FORTRESS (SAN RAINERI PENINSULA, MESSINA, SOUTH ITALY): FIRST RESULTS AND GEOARCHAEOLOGICAL IMPLICATIONS – ID 1847

*C. Bottari, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Bottari, Osservatorio Sismologico Di.C.T.A., Italy*
*P. Carveni, Dipartimento di Scienze Geologiche, Italy*

SS. Salvatore fortress is a magnificent Angevin building built at the beginning of the 16th century and placed in San Ranieri peninsula. The fortress includes inside a medieval tower. The strategic location of these buildings, internal to the harbour military zone, precluded for long time the possibility to investigate them. Recent geophysical investigations carried out on the perimeter

walls of the fortress and on the foundation soils, pointed out seismic damage and soils subsidence which can be correlated with geoarchaeological characteristics of the site. In Antiquity the fortress was affected by numerous phases of destructions and reconstructions which can be assigned to either anthropic causes or seismic shakings or remodelling to follow military needs. Due to the lack of trustworthy data on the type of damage the fortress suffered, we focused on the macroseismic study of the strongest earthquakes which heavily damaged the Straits of Messina. The modelling shows the earthquakes that have more stressed San Raineri peninsula and particularly the fortress. The differential settlement of the foundation soils produced a difference in level of the original topographic surface on which the medieval tower and the fortress lean, as well as cracks along the external walls which are probably caused by the slip of the fault that crosses San Ranieri peninsula soils. To verify whether the observed damage is correlated with the activity of this fault, a detailed morphotectonic study of the harbour of Messina was carried out. The investigation, supported also by geognostic borings and geophysical survey, indicates that San Ranieri peninsula constitutes the emergent portion of a submarine horst. Such a horst is bounded by active faults orthogonally oriented to coastline that cut the NNE-SSW en échelon faults system which lowers the hills of Mt. Peloritani toward the sea and thus modelling the coastline of the town.

## ESTIMATING MACROSEISMIC INTENSITY FROM DOCUMENTARY SOURCES USING FUZZY SETS – ID 1871

*D. Tripone, Dip. di Fisica - Università di Bologna, Italy*
*G. Vannucci, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*P. Gasperini, Dip. di Fisica - Università di Bologna, Italy*
*G. Ferrari, SGA Storia Geofisica Ambiente, Italy*

Seismic intensity of historical earthquakes is usually assessed from documentary sources by the expert evaluation of the correspondence of reported effects with the descriptions of the adopted macroseismic scale. This process involves a number of subjective assumptions, not always explicitly stated, that sometimes may bring different experts to discrepant outcomes. We already proposed a decision making method, based on the fuzzy set theory and computer-aided procedures that can be successfully used to objectively assign macroseismic intensity. This approach is structured in three main steps: 1) the creation and computer coding of a dataset of effects for each locality, 2) the formulation of a set of rules to equate formally distinct macroseismic descriptions actually corresponding to the same effect 3) the application of a decisional algorithm to assign the intensity. The first two steps have now been improved and made friendlier, with respect to previous works, by the use of MS-Excel macros for data collection and management. We also applied and compared different decision algorithms and defuzzyfication methods using the data of some earthquakes of last century in Italy. Our analysis highlighted "strong" effects well correlated with a specific intensity degree for all the analyzed earthquakes and other "weak" effects which association with the intensity degrees depends on the considered earthquake.

## ESTIMATING LOCATION AND SIZE OF HISTORICAL EARTHQUAKES BY GEO-ARCHAEOLOGICAL STUDY OF UM-EL-KANATIR, DEAD SEA FAULT – ID 1889

*N. Wechsler, Tel Aviv University, Israel*
*O. Katz, Geological Survey of Israel, Israel*
*S. Marco, Tel Aviv University, Israel*

We analyze an archaeological site of Um el Kanatir, which was damaged by a seismogenic landslide. We use the landslide mechanical character to constrain historical seismic-acceleration along the DSF. Um el Kanatir is a Byzantine (6th century) archeological site 10 km east of the DST in northern Israel. Its location on the slope of a canyon and the marly bedrock make it susceptible to landslides. The excavations revealed typical earthquake-induced damage in the archaeological structures, including a displaced water trough, but no significant geological fault is found. Because landslide topography is recognized near the damaged water system we interpret the damage to have been caused by a seismogenic landslide. We calculate the critical acceleration ac for landslide triggering from the factor of safety FS. The resulting high values of FS ($> 2$) require strong horizontal acceleration to induce slope-instability, indicating that the slope is generally stable and that a strong earthquake is needed in order to cause failure. We use the Newmark displacement (DN) method following Jibson et al. (2000) empirical equation: log DN = 1.521log Ia 1.993log Ac 1.546 If DN=10 cm is the failure criterion, and given that the Aries intensity Ia in the region (Zion et al. 2004) is: log Ia = 1.2Mw 2.2log R 4.9 we can calculate the magnitude MW as a function of distance (R) from the source. The results show that an Mw $> 6.8$ earthquake within 50 km from the site triggered the landslide. Archaeological findings indicate that the site was abandoned in the late 8th Century, therefore the candidate earthquakes are the 749, 1202 and 1759 AD earthquakes. Assuming that the destruction forced the abandonment we suggest that the damage was caused by the 749 AD earthquake.

* N. Wechsler is now at the University of Southern California.

## COMBINING GEOLOGICAL, ENGINEERING, AND PALAEO- AND ARCHAEO-SEISMIC STUDIES IN ISRAEL – ID 1904

*S. Marco, The Department of Geophysics, Tel Aviv University, Israel*

In order to obtain reliable estimates of the rupture locations and other earthquake characteristics we review historical accounts, perform on-fault and off-fault palaeoseismic and archaeological studies, and analyze damage in ancient buildings using the DDA code. We have recovered the rupture locations of the earthquakes of January 749, May 1202, and October 1759 and analyzed damage of several others. Assuming the same reliability for other historical cases we estimate the locations of the known strong earthquakes of the last two millennia in Israel, based on historical texts. Bearing in mind the uncertainties associated with the interpretation of historical accounts, we discern distinct short-lived patterns of earthquake occurrence. One example is an almost periodic recurrence of large earthquakes between the Dead Sea and the Sea of Galilee starting with the 31 BC earthquake and continuing with the AD 363, 749, and 1034. Two smaller earthquakes of 1546 and 1927 followed, altogether exhibiting a mean recurrence interval of 390±80 years. This pattern is not observed elsewhere along the Dead Sea Fault. Another observed pattern is a sequence of north-to-south progressive failures that occurred once in 859, 991, 1033, and 1068 and again in 1170, 1202, and 1293. No similar patterns are observed before or after these two series. The quasi-periodic and sequential failure patterns appear to last only short periods of the order of several decades to a few centuries. Our interpretation also shows that it has now been eight centuries since most of the Dead Sea Fault plate margin in Israel sustained significant rupture. A conspicuous seismic gap is noticed in the northern Jordan Valley and possibly also in the Arava Valley, where information may suffer from incomplete reporting.

## STRUCTURAL DAMAGE FROM EARTHQUAKES IN THE 2ND-9TH CENTURY AT THE ARCHAEOLOGICAL SITE OF AILA ON THE DEAD SEA TRANSFORM IN AQABA, JORDAN – ID 1921

*T. Niemi, University of Missouri, United States*
*R. Thomas, University of Southampton, UK*
*S. T. Parker, North Carolina State University, United States*

The ancient ruins of the city of Aqaba are located at the head of the Gulf of Aqaba along the seismically-active, Dead Sea transform fault in southern Jordan. Detailed archaeological excavation, architectural surveying, and geologic mapping were conducted along active faults that cut through 2nd to 9th century deposits at the archaeological site of Aila. Stratigraphic evidence for ground-rupturing earthquakes and the associated structural collapse, damage, and repair were documented for a multiphase mudbrick complex. Fractures in the walls and corner joins had opened up sometime in antiquity and had been patched by cobbles and pebbles in a matrix of mud placed into the fissures. These

repairs have reactivated in later earthquakes and appear today as open cracks along the margins of the repair. Intense ground shaking and subsidence of the structure across the active fault has also caused fracturing and localized structural collapse of the building. Northeast-southwest directed tension due to subsidence along the fault has also created northwest-trending extensional fractures and diagonal cracks. The southwest side of the structure is built across active fault strands and provide piercing lines to measure coseismic slip. Offsets ranging from 12 to 54 cm record predominately dip slip. Our data indicate that there have been seven earthquakes that have disrupted the archaeological deposits since the second century A.D. based on evidence of faulting. Age constraints on the timing of these seismic events are provided by ceramic, coin, and artifact identification. Major seismic activity is present at our site in the 4th, 7th, and sometime after the 9th centuries. These data suggest that historical earthquake catalogues are incomplete with regard to some of the less damaging earthquakes that have affected southern Jordan but may have played a significant role in the cultural history and present day seismic hazards of the region.

### THE ELEMENTARY CELL OF THE HISTORICAL-SEISMOLOGICAL ARCHIVE – ID 1953

*P. Albini, INGV, Italy*
*P. Migliavacca, INGV, Italy*
*A. Rovida, INGV, Italy*
*M. Stucchi, INGV, Italy*

According to the modern standard, historical-seismological data are processed in terms of macroseismic intensity and located in time and space; the elementary cell of the macroseismic intensity database is the intensity datapoint. These cells are robust enough to allow seismologists and engineers to build upon them; earthquake parameters can be determined using formalised procedures, relationships with shaking parameters can be established. The most important point is that, when the power is switched off and then turned on next morning, or next month, data are still there, there is no need to remember why on earth that location, or that size, was assessed. But, from what, and how, those intensity data points were derived? Would we assess the same intensity value, or associate that historical record to the same location, or time, to which we – or someone else – associated it last time? Here we are in trouble. Modern historical seismological studies give references; they consist of volumes, or part of them. Many studies give the texts used for assessing intensity; but in many cases, references and texts are many, for the same locality/earthquake. In some cases, things are such that one would assign exactly the same intensity and refer it to the same locality; in some other cases one would probably change his mind. Modern macroseismic investigation, either performed in the field or by means of questionnaires, usually leaves elementary cells, in terms of forms. Although not always very detailed, they represent the piece of information upon which the intensity datapoint is built. In this paper we propose a form aimed to make explicit, and to preserve for the future, the basic information, the considerations and the procedures used to give birth to every single intensity datapoint, that is the assessment of location, time and intensity of the earthquake effect.

### ARCHAEOSEISMOLOGICAL ANALYSIS AND NUMERICAL MODELLING OF THE GREAT THEATRE OF LARISSA (THESSALY, GREECE) – ID 2058

*R. Caputo, University of Basilicata, Italy*
*D. Liberatore, University of Basilicata, Italy*
*K. G. Hinzen, Cologne University, Germany*
*M. Mucciarelli, University of Basilicata, Italy*
*G. Spera, University of Basilicata, Italy*
*P. Sarubbi, University of Basilicata, Italy*
*A. Tziafalias, Dept. of Prehistorical and Classical Antiquities, Greece*
*B. Helly, Maison de l'Orient Méditerranéen "Jean-Pouilloux", France*
*S. Schreiber, Cologne University, Germany*

Larissa, the third major town of Greece, is located in Northern Thessaly along the southern border of a Late Quaternary graben. In particular, morphotectonic, geophysical and mainly palaeoseismological investigations clearly documented the occurrence of moderate-to-strong earthquakes during Holocene time. The seismotectonic behaviour of these active structures is characterised by recurrence intervals of few thousands of years, though both instrumental and recent historical data suggest a seismic quiescence, at least during the last 4-5 centuries. The present research, based on an archaeoseismological approach, is devoted to improve our knowledge on the past earthquakes, which occurred in the area. As a case study, we selected the Great Theatre of Larissa, originally built at the beginning of the 3rd century BC. Historical and archaeological investigations documented a deep re-handling and retrofitting of the monument during the 2nd-1st century BC likely impelled by the occurrence of a destructive earthquake. However, the recent excavation of the theatre highlighted the occurrence of important structural damages also affecting the renewed building and likely due to seismic ground accelerations. Probably the most important and more impressive damages are represented by the displacement and rotation of some of the blocks of the walls and the rupture of some of the blocks. In order to infer the peak ground acceleration at the site, we carried out a numerical modelling of the scene building. A numerical model has been set up, with the aim to simulate the seismically induced in-plane sliding. The seismic action assumed for the analysis has been generated according to a model of fault rupture, wave propagation and wave filtering in the surface layers. The results of the numerical modelling are similar for the different walls and confirm the occurrence of important sliding effects along bed joints of the two upper corner sectors of the walls.

## SC-B 1: Theory of Wave Propagation and New Techniques of Data Processing
Level 2

### ARRAY ANALYSIS OF EARTHQUAKES IN PUGET SOUND, WASHINGTON. NEW INSIGHT ON THE ERROR ESTIMATE AND PROBABILISTIC SOURCE LOCATION – ID 1675

*M. La Rocca, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*D. Galluzzo, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*S. Malone, University of Washington, United States*
*W. McCausland, University of Washington, United States*
*G. Saccorotti, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*M. Ciampi, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*
*E. Del Pezzo, Istituto Nazionale di Geofisica e Vulcanologia -OV, Italy*

Several tens of local and regional earthquakes recorded by three seismic arrays in Puget Sound area have been analyzed using array and polarization methods. We applied the Zero Lag Cross-Correlation tachnique to estimate apparent velocity and propagation direction of the correlated signals, and the covariance matrix method to estimate polarization properties of the wavefield. Results of array analysis for both P and S waves have been compared with the expected backazimuth and slowness computed from the hypocenters coordinates. Comparison of backazimuth and slowness shows a very good agreement for the most of analyzed events. Only in few cases the differences exceed 15 degrees in backazimuth or 0.04 s/km in slowness. Statistical analysis of the results gives sigma_BP = 10° and sigma_BS = 8° as standard deviations for the backazimuth and sigma_SP = 0.021 s/km and sigma_SS = 0.033 s/km for the slowness results, for P and S phases respectively. These values are consistent with the theoretical relation among slowness, backazimuth and their uncertainties. Theoretical array response spectra have been computed by the analysis of the same signal arriving at the same time at any

stations of the array. Individual distributions of backazimuth and slowness differences at each array are consistent with the expected results inferred by the theoretical array responses. Theoretical errors on backazimuth and apparent velocity as functions of the signal slowness have been computed. The comparison of standard deviations sigma_SP = 0.021 s/km and sigma_SS = 0.033 s/km, associated with the average slowness S0P = 0.128 s/km and S0S = 0.224 s/km estimated by the P and S waves distributions, shows a very good agreement with the theoretical error prediction. Finally, the correlation range around the maximum of the slowness spectra in which the true solution is included has been estimated for each array at a given frequency.

## DISCRIMINATION OF LOCAL EVENTS IN THE NORTHERN DEAD SEA FAULT REGION USING PATTERN RECOGNITION SCHEMES – ID 1704

*S. Barzilai, NDC, Israel*
*G. H. Wust-Bloch, Tel Aviv University, Israel*
*Y. Ben-Horin, NDC, Israel*
*Z. Ben-Avraham, Tel Aviv University, Israel*

The identification of "man made" signals is essential for the production of reliable seismic catalogs for hazard assessment purposes and supports the verification tasks of the "Comprehensive Nuclear Test Ban Treaty" (CTBT). For regional events, traditional discrimination methods rely on phase/spectral ratios or velograms with specific band filters. The approach followed here to discriminate weak seismic events at local distances relies on broadband self-adaptive filters (Sonograms), which permit a complete analysis of the full signal energy, and on pattern recognition method, using SONODET software (Joswig, 1999). The method was tested in the northern Dead Sea fault region because is has active local microseismicity and frequent blasting activity at several quarries. A catalog of over 100 events (earthquakes, explosions and possible explosions) generated within 30 km radius from MMAI array (MMA0-vertical channel) was designed for the analysis (January 2004 to January 2006). Blast events are from six active quarries with complete azimuthal coverage. One single MP (master pattern) was selected for each quarry. Despite the variability of natural seismicity, it was also possible to select a single representative MP for weak earthquakes. The initial results show that path dependency is negligible but discrimination performance remains distance sensitive. Using Amiad_10 MP as a single discriminator gives 74% successful recognition for the blast events. Earthquake_13 gave 95% successful recognition for natural seismicity. The remaining 5% gave no identification. No misclassification was fined. Further testing showed that discrimination performance could be further improved by applying MP sets: Using both Amiad_10 and Golani_14 MP's gave 95% successful recognition for the blast events. A higher recognition rate can be obtained by using multiple MP's. Preliminary results show high performance variability when transporting MP from horizontal to vertical traces. On-going tasks deal with the development of horizontal-vertical discrimination schemes and further optimizing distance robustness for MP.

## CONVERTED AND REFLECTED WAVES FROM LOCAL EARTHQUAKES – ID 1753

*J. Malek, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*J. Horalek, Institute of Geophysics AS CR, Czech Republic*

Local earthquakes in the West Bohemia swarm region are a unique source of S waves, which can be used for structural studies. We have studied seismograms from local earthquakes recorded at stations of the local network WEBNET during earthquake swarm in the year 2000. To this purpose about 60 earthquakes with similar focal mechanisms were selected. Hypocentre of all the earthquakes are located on the same fault plane inside the square of about 800 x 800m. Both P-and S-wave onsets were used for precise relative localization using the double difference algorithm. Thus we reached the relative location accuracy of 20m in both epicentre coordinates and depth. The seismograms were summed with time delays corresponding to the direct S wave propagating upwards. The summed seismograms exhibit very clear SP converted wave, which is obvious mainly on the vertical component before direct S onset. The time difference between the converted and direct waves varies significantly for the individual WEBNET stations. That is interpreted as an inclined velocity interface at the depth of several kilometres. We also summed the seismograms with time delays corresponding to the S-wave propagating downwards. In this case, signal to noise ratio was further improved by means of the non-linear filtering. In this way reflections from Moho were identified and the depth of the Moho was estimated at 29 km.

## STRATIFIED S-VELOCITY ESTIMATION FROM P-WAVE APPARENT INCIDENCE ANGLES – ID 1757

*L. Svenningsen, University of Aarhus, Denmark*
*B. Holm Jacobsen, University of Aarhus, Denmark*

The motion of the free surface due to an incident wavefront defines an apparent incidence angle which differs from the wave's real incidence angle. This effect is caused by the interference of reflected P- and S-waves at the free surface. For a P-wave incident in a halfspace the free surface effect depends only on the S-velocity. As a result the S-velocity of the halfspace can be calculated given the slowness of the P-wave and it's apparent incidence angle as observed on the surface. When the subsurface is stratified the apparent incidence angle varies with the frequency content of the incoming signal.

We present a simple and efficient method for estimating apparent incidence angles and thus apparent S-velocities as a function of the upper frequency. These estimates are best performed on ZRT-receiver functions.

We also present an efficient approximate inversion technique to convert apparent S-velocity estimates from a function of frequency to a function of depth.

Our synthetic tests confirm that the apparent S-velocity estimate for the high frequencies is most sensitive to the layers close to the surface, whereas estimates for successive lower frequencies has increasing sensitivity to deeper layers.

We test this new method on data from three different permanent broadband stations: Black Forest Observatory (BFO) and Fürstenfeldbruck (FUR) both in Germany, and "Summit" (SUMG) situated centrally on the thick greenlandic ice sheet. The resulting S-velocity models expose clearly the expected differences between the station locations (i.e. different sediment/ice thicknesses and Moho depths).

We believe that the suggested technique is an attractive supplement to the portfolio of existing techniques applied as a standard to high quality three component broad band teleseismic data.

## SPECTRAL ELEMENT MOMENT TENSOR INVERSION OF REGIONAL WAVEFORMS IN THE ALPINE-APENNINIC AREA – ID 1845

*D. Stich, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. Pondrelli, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Morelli, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

Seismic wave propagation through the Alpine-Apenninic area is conditioned by relevant lateral variability in earth structure, including large variations of crustal thickness, and deep sediment basins in the forelands of mountain belts. Regional seismic moment tensor inversion, however, is still based on significantly simplified earth models. In this way, inversion remains restricted to a relatively long-period band of observed waveforms, which is less sensitive to heterogeneity in structure. Here, we consider seismic wave propagation in a 3D heterogeneous lithospheric model, to obtain a better precision in predicting the intermediate period wavefield. We synthesize an a priori earth model for the Alpine-Apenninic region, and use the spectral element method for numerical simulation of the wavefield out to 1000 km epicentral distance. Simulations are computed on a 100 cpu cluster of Linux PCs. We show snapshots of forward simulations to illustrate the effect of lateral heterogeneity on wave propagation. For the inverse problem, we compute Fréchet derivatives of waveforms with respect to the six independent moment tensor elements, at several trial depths, from the local

strain tensors obtained from reciprocal single force simulations for switched source and receiver geometries. We apply 3D moment tensor inversion to six recent moderate earthquakes (magnitude 5) from northern Italy, France and Slovenia, and their respective aftershocks (magnitudes > 3.5). We show how we can usually match observed waveforms in a broad period band from 100 s to 15 s. The resolution of depth, fault angle parameters and non-double-couple components improves significantly for shorter periods, leading to better constrained source estimates for the moderate earthquakes. Also, we observe a better quality of recorded aftershock waveforms in a shorter period band, indicating the potential of 3D inversion in extending moment tensor catalogues to small regional earthquakes in structurally heterogeneous environments.

### CRUSTAL STRUCTURE OF THE TRANSITION ZONE BETWEEN THE SAXOTHURINGIAN AND MOLDANUBIAN UNITS STUDIED BY THE SURFACE WAVE METHOD – ID 1851

*P. Kolinsky, Institute of Rock Structure and Mechanics AS CR, Czech Republic*
*J. Malek, Institute of Rock Structure and Mechanics AS CR, Czech Republic*

A profile of four broadband seismic stations is used to study the transition zone between the Saxothuringian and Moldanubian units (Czech Republic). The profile is about 120 km long and its direction is SE-NW. Both earthquakes from SE (Greece, Turkey and Iran) and NW (Mexico, Calfornia) were recorded with clear surface wave groups. Time-frequency analysis and multiple filter technique were applied to obtain dispersion curves. The phase velocities of fundamental modes of Rayleigh and Love waves along the profile were determined and inverted to obtain the S-wave seismic velocity in the Crust. The results are compared with P-wave velocity model obtained during refraction experiments and with results of the receiver function methods.

### A COMPARISON OF TRAVELTIME MODELING SCHEMES – ID 1867

*F. Louis, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*

The process of seismic modelling is a significant task in procedures like migration, tomography and earthquake relocation. The accurate knowledge of ray paths and the precision of first arrival travel times have a direct effect on the above processes. The performance of a variety of travel time modelling schemes is evaluated using numerical simulations. The methods tested, are mostly chosen since they are implemented in many inversion and imaging algorithms. The ability of each scheme to predict travel times is tested at the cases of simple two dimensional P-wave velocity parameterizations. The methods considered include: an eikonal solver (FD approach), a shortest path method (SPM), and a two point ray tracing technique (TPRT). Quantitative comparisons among the forward modeling approaches are based on the data misfit, CPU time, number of model parameters and the velocity contrast. When a homogeneous model is utilized the FD solver is giving results within tolerance in opposition to the TPRT and SPM schemes where the time error is lower. When the model parameterization is finer, FD remains the most efficient in computer time but still suffers in the error distribution. In a two layer case the error from FD calculations is increasing when the velocity contrast is high. A drop in the misfit is observed in the far field and the method is still computationally faster. SPM calculations are independent from the model whereas the error is mostly related to the number of possible routes. The TPRT approach performs better in smooth velocity distributions and the time misfit is strongly associated with the distance from the source.

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### A NEW TWO STEP CORRELATION BASED TECHNIQUE FOR THE CLASSIFICATION OF SEISMIC EVENTS – ID 1986

*V. Pikoulis, Dept of Computer Engineering and Informatics, Greece*
*E. Psarakis, Dept of Computer Engineering and Informatics, Greece*
*E. Sokos, Laboratory of Seismology, Greece*

The grouping of seismic events that have similar characteristics constitutes a challenging problem, which is of great importance in seismotectonic studies involving event relocation and in automatic classification problems. Due to a number of reasons, such as the special nature of the recorded signals as the superposition of P, S and surface waves and their different energies' scale, the uncertainty in the detection of P and S arrival times, the special meaning of the form of the P - wave coda in deciding the similarity of events, solving such a problem is not an easy task. The key point in solving the problem, is the use of an appropriate measure that will be capable taking into account all the afore mentioned particularities, arising in the problem. Moreover, the invariance of the similarity measure to both scale and dc-offset distortions as well as its capability in producing fractional accuracy in translation parameter, are two desired features in this class of problems. In this work, we propose a new two step procedure that results in a robust classification technique. Our classification uses a correlation based measure which is a nonlinear function of the translation parameter and incorporates most of the desired requirements. According to the proposed technique a well defined optimization problem is solved for the optimal alignment of the profiles, in the first step, and the construction, in a sample by sample basis, of the cross - correlation function of the two profiles, in the second one. Our decision is then based on the statistical properties of this function. Preliminary simulation results from the application of the proposed technique, in a number of benchmark seismological data sets, reveal that the proposed technique outperforms well known correlation based techniques.

## SC-C 0: Physics of the Earthquake Sources (Open Session – Posters Only)

Level 2

### SOURCE PARAMETERS OF THE 2004 KALININIGRAD EARTHQUAKES – ID 604

*B. Domanski, Institute of Geophysics, Poland*

An analysis of source parameters of the two unexpected earthquakes from the Kaliningrad (Russia) area is presented. The earthquakes occurred on the 21 September 2004 at 11:05:01 and 13:32:31 UTC, respectively. The first event was located at the latitude of lat=54.924 deg N and the longitude of lon=20.120 deg E, with a depth of d=16 km, and the second event was located at of lat=54.876 deg N, lon=20.120 deg E and d=20 km. Moment magnitude of both earthquakes was quite similar, equal to 5.1 and 5.2, respectively. The values of magnitude reported by various seismic organizations, however, differed significantly. This discrepancy could be explained by the high-frequency motion observed on the vertical components of S waveforms at some seismic stations. These stations are situated along the direction specified by two, opposite with respect to the source, stations: BLEU in Sweden and SUW in Poland. The high-frequency components are characterized by 6-8 Hz motion for the first event and by 2-4 Hz motion for the second event, distinctly visible on the spectrograms of ground velocity and ground displacement. The values of magnitude calculated at such stations from S-wave amplitudes or from seismic spectra are clearly overestimated and are close to 6. For the analysis of spectral and source parameters, therefore, a careful selection of seismic records was necessary.

### THE PECULIARITIES IN THE SEISMIC REGIME AT DIFFERENT THERMODYNAMIC CONDITIONS: NEW CORRELATIONS – ID 1041

*M. Rodkin, Geophysical Centre RAS, Russian Federation*

To investigate the change in the seismic regime at different thermodynamic conditions a few unused earlier parameters (the difference in the origin time and depth of the earthquake determined as the hypocentre parameters and as the seismic moment solution, and the mb/mw ratio value) were used in combination with the routinely used ones (the change in the earthquakes density with depth, and the apparent stress and b-values). The additional new parameters give possibility to characterise the direction of spread of the earthquake failure and the relative contribution of the high- and lower frequency modes in seismic radiation. The parameters values were averaged in the depth intervals sufficient to obtain their robust estimates. The tendencies in change of the parameters with depth, and the interrelations between different parameters were analysed. A number of correlations between the parameters examined were revealed. Some of the correlations testify for the contribution of the deep fluid in the earthquake origin and in failure development both for the cases of the crustal and mantle earthquakes. The specific features in the deep seismic regime coincident with the depth of the main phase transformations were revealed also. The correlations obtained and their interpretation are discussed.

### KALININGRAD SEPTEMBER 21, 2004 EARTHQUAKE SEISMOTECTONICS – ID 1521

*B. Assinovskaya, Central astronomical observatory at Pulkovo, Russian Federation*

The problem is what fracture zone was responsible for Kaliningrad earthquakes September 21 2004 occurrence? The macroseismic and instrumental earthquake location data differ essentially. Instrumentally, both events seem to connect with the Pregolja E-W directed normal fracture zone. But focal mechanism solutions show mainly strike-slip type deformations along possible N-E or N-W fault planes. Macroseismically, the first event occurred offshore to the west from Jantarny. There are some evidences that the second source was located 4-6 km to the north from the first one. The study of geological and geophysical data allowed supposing of N-E direction dislocation zone at a distance of 3-5 km offshore that stretches along the eastern side of the Gdansk depression. Tectonic activity of this fault is confirmed by existence of numerous valleys thick with Quaternary sediments. The western polish side of the depression is formed by a whole system of active N-S dislocations. Besides, the Kaliningrad earthquake has a feature that distinguishes it from Fennoscandian type events. The latter usually occur under comparatively low crust temperature conditions when heat flow amounts not more 30-40 mW/m2. But heat flow reaches 70 mW/m2 and even 90 mW/m2 within the south-eastern Baltic coast and the Neman fracture zone respectively. The heat anomaly here is connected with an area of partial melting in the low crust. There is a data of heat earthquake precursor. In fact, hot water appeared in a well at Lesnoy on Kurch Spit in winter 2002. After earthquake heat activity showed itself in the form of a great steam rejection through a weak ground zone at Romanovo. The temperature values exceed 400°C at a depth of 20 km around the source crust that prevents deep located earthquake occurrence.

### SOURCE PROCESS OF THE 8 OCTOBER 2005, PAKISTAN EARTHQUAKE FROM TELESEISMIC OBSERVATION – ID 1575

*S. Ozcelik, Istanbul University, Turkey*
*H. Alp, Istanbul University, Turkey*
*A. Pinar, Istanbul University, Turkey*

On 8 October, 2005 a big size earthquake hit in northern Pakistan, hence we investigate the source rupture process of this event, Pakistan, Mw=7.5 earthquake through inversion of teleseismic broadband body waves. The source rupture process is examined using P and SH components observed at epicentral distances between 30 and 90 degrees were used for inversion with good azimuthal coverage recorded by the IRIS Global Seismic Network. Two subevents were necessary to explain the observed seismic records with total seismic moment of Mo=1,82e+27 dyn.cm and so, which gives a moment magnitude Mw of 7.5. The major energy release was found to be during the first subevent with seismic moment of Mo=1,10e+27 dyn.cm. We also were solved the big aftershock (M6.3) which is took place nearly the main event. we have offered the first step of our results.

### USING THE RECURRENT METHOD FOR SEISMOLOGY PROBLEMS – ID 1622

*D. Malytskyy, CB IGPH NASU, Ukraine*
*R. Pak, CB IGPH NASU, Ukraine*
*O. Mujla, CB IGPH NASU, Ukraine*

Studying spectral and dynamic parameters of earthquake sources is an essential condition to solve many problems of seismology. Physical properties of a medium as a function of stress must be studied in order to understand physical processes run near the source A method of solving direct problems is proposed and presented in the form of recurrent relationships. The equations obtained are suitable for numerical calculations. We obtain the exact solution for free surface displacements generated from a point source in a layered medium. In general earthquake sources are introduced by seismic moment tensor. We use the Bessel – Laplace transform for displacement potentials from which the displacements follow by spatial differentiation. The components of the seismic moment tensor are a function of time. It should be noted that wave field values on a free surface are obtained as strict recurrent analytical relations.

### SOURCE PARAMETERS OF LOW MAGNITUDE EARTHQUAKES OF VRANCEA REGION (ROMANIA) – ID 1647

*L. A. Ardeleanu, National Institute for Earth Physics, Romania*

The seismic moment tensor for a set of small earthquakes with local magnitudes between 2.4 and 3.8, located in the crust (hypocenter depth in the range 7 to 39 km) at the bending of the Eastern Carpathians, is determined by high frequency waveform modeling. Observed data are short period velocity seismograms, vertical component, recorded at epicentral distances up to 150 km. Since the complexity of the observed waveforms makes difficult the identification of individual phases, a method based on the synthesis of the complete wavefield is used in the forward modeling: the Green's functions are computed by multimodal summation in layered anelastic media. A major drawback of this approach is the oversimplification of the medium structure, rather complex in the study area. We modeled grossly the lateral variations by using a specific 1-D approximation for each source-station path. The seismic moment tensor and its reliability are estimated following a bootstrap-like procedure: a set of solutions of the inverse problem are determined using different subsets of the complete data set, then the consistent individual solutions are averaged. The distribution of the principal axes from individual subsets provides also an estimate of the confidence of the average fault plane solution. The focal mechanisms retrieved indicate a dominant strike-slip faulting for all the investigated events. The orientation of the acceptably constrained principal axes points out a complex deformation field in the crust in the Vrancea region.

### IDENTIFICATION OF THE FAULT PLANE AND A SIMPLE 3D VISUALIZATION TOOL – ID 1685

*P. Adamova, Charles University, Faculty of Math. and Phys., Czech Republic*
*J. Zahradnik, Charles University, Faculty of Math. and Phys., Czech Republic*

Quick identification of the fault plane plays a vital role in several seismological applications, such as: (i) computer simulated shake maps for post-earthquake emergency, (ii) Coulomb stress

calculations to assess regions of increased aftershock probabilities, etc. Actions like that cannot be postponed until mapping the fault plane with aftershocks. Fortunately, readily available after a M>5 event are the hypocentre position (H), centroid position (C) and the moment tensor, hence two nodal planes (NP1, NP2 passing through C). This contribution emphasizes usefulness of their combined use. Obviously, H should lie in NP1 or NP2 and, therefore, should help in distinguishing which of the nodal planes is the fault plane. As a rule, this trivial idea is ignored, or at least not massively used. It is because of inaccuracies in the mentioned parameters and due to lack of a simple 3D visualization. Thus we suggest the following innovation. First, H and C have to be retrieved in the same crustal model. Second, varying free parameters of the two inverse problems should provide the uncertainty estimate. Third, mutual geometrical configuration of H, C, and NP1, 2 (and their uncertainties) should be carefully analyzed, using simple 3D animation. We propose animation based on free software (Gnuplot); data preparation is a task of a minute. Finally, in favorable cases, hypocenter appears on (or closer to) one of the nodal planes, thus indicating the fault plane. Verification is done by forward wavefield simulation for a simple finite-extent source model. Method has been applied to several M>5 earthquakes in western Greece, including the M6.7 Cythera event of January 8, 2006 in southern Aegean Sea.

### MOMENT TENSOR INVERSION OF POSSIBLY MULTIPLE EVENTS AT REGIONAL DISTANCES – ID 1731

*P. Adamova, Charles University, Faculty of Math. and Phys., Czech Republic*
*J. Zahradnik, Charles University, Faculty of Math. and Phys., Czech Republic*
*G. Stavrakakis, National Observatory of Athens, Inst. of Geodyn., Greece*

Moment tensor inversion of possibly multiple events is studied. All experiments are performed with new code ISOLA, based on time-domain iterative deconvolution of multiple point-source subevents. It is extension of Kikuchi and Kanamori (1991) for complete waveform inversion of regional data (Zahradník et al., 2005b). The inversion is tested and applied to three selected M5 events from western Greece: on the island Lefkada (an aftershock of August 14, 2003), near the town Amfilochia (December 31, 2002) and near the town Vartholomio (December 2, 2002). High non-shear CLVD component was reported by major agencies for two of the events (Amfilochia and Vartholomio). Both these earthquakes have been interpreted as double events. Methodical lessons emerging from the applications are formulated.

### SURFACE WAVE TOMOGRAPHY OF THE EUROPEAN ARCTIC – ID 1744

*J. Schweitzer, NORSAR, Norway*
*C. Weidle, University of Oslo, Norway*
*A. Levshin, University of Colorado, United States*
*N. Maercklin, NORSAR, Norway*
*N. Shapiro, Institut de Physique du Globe, France*
*M. Ritzwoller, University of Colorado, United States*

Existing global and regional tomographic models have limited resolution in the European Arctic due to the small number of seismic stations, relatively low regional seismicity, and poor knowledge of the crustal structure. During the last decades, new seismic stations were permanently ortemporarily installed in and around this region. To improve the surface wave data set in the region, we extensively searched for broadband data from stations in the area from the beginning of the 1970s until 2005 and were able to retrieve surface wave observations from the data archives at NORSAR, the Universites of Bergen and Helsinki, the Kola Science Center in Apatity, the Geological Survey of Denmark and Greenland, and from IRIS and GEOFON. Recently, a new crustal model of the Barents Sea and surrounding areas had been derived in a joint Norwegian-American project. This detailed information on crustal thickness and sedimentary basins helps to constrain the tomographic inversion of the upper mantle velocity structure based on surface wave data. Rayleigh and Love wave group velocity measurements from 10 to 150 sec period obtained on the newly retrieved data were combined with existing data provided by the University of Colorado. Using these data, we constructed a new 3D shear velocity model of crust and upper mantle beneath the European Arctic, which provides higher resolution and accuracy than previous models. The new model reveals substantial variations in shear velocities in the upper mantle across the region. Of particular note are clarified images of the mantle expression of the continent-ocean transition in the Norwegian Sea and a deep high wave speed lithospheric root beneath the Eastern Barents Sea. Currently, the data set is being extended southwards to cover mainland Scandinavia and leading to a 3D model of the crust and upper mantle for Norway and adjacent areas.

### NON-DC MECHANISMS OF MICROEARTHQUAKES INDUCED DURING THE 2000 INJECTION EXPERIMENT AT THE KTB SITE, GERMANY – ID 1765

*V. Vavrycuk, Geophysical Institute, Czech Republic*
*M. Bohnhoff, GeoForschungsZentrum Potsdam, Germany*
*Z. Jechumtalova, Geophysical Institute, Czech Republic*
*P. Kolar, Geophysical Institute, Czech Republic*
*J. Sileny, Geophysical Institute, Czech Republic*

Moment tensors of microearthquakes induced during the 2000 injection experiment at the KTB deep drilling borehole at a depth level of 5.4 km are studied. A family of 37 most reliable moment tensors contains significant non-double-couple (non-DC) components. The DC is on average 60% and the non-DC is 40%. The non-DC components contain both the isotropic (ISO) and compensated linear vector dipole (CLVD) components. The mean value of ISO is 1.5%, the mean value of CLVD is -5.7%. The predominantly negative CLVD components are inconsistent with the concept of the non-DC mechanisms as a result of tensile faulting due to fluid injection into the rock. The non-DC components have probably three other major origins: random numerical errors produced by the moment tensor inversion due to noise and limitations of input data, systematic errors produced by mismodeling of the medium when calculating the Green functions, and anisotropy in the focal area. Anisotropy is a very likely origin of non-DC components, because a rather strong seismic anisotropy has been observed at the KTB site with strength up to 20% for P waves, and attributed to foliated crystalline rocks composed of gneiss and amphibolite. We have employed the non-DC components for estimating an optimum orientation of anisotropy in the focal area. The optimum orientation of the symmetry plane of anisotropy is nearly vertical with a strike of N335°-340°E. This strike coincides well with strikes typical for many major lithological units and faults in the area.

### RUPTURE PROCESS OF THE M7.6 KASHMIR EARTHQUAKE OF 8 OCTOBER 2005 FROM TELESEISMIC WAVEFORM ANALYSIS – ID 1804

*J. Borges, Centro de Geofísica de Évora, Portugal*
*M. Bezzeghoud, Centro de Geofísica de Évora, Portugal*
*B. Caldeira, Centro de Geofísica de Évora, Portugal*

On Saturday October 8, 2005 at 03:50:38 (UTC) a magnitude 7.6 (USGS) earthquake struck Pakistan and parts of India and Afghanistan and It was felt in major cities, including Islamabad and Lahore, and India's capital of New Delhi. Its epicenter is about 90 km north-northeast of Pakistan's capital, Islamabad. At least 80,000 people was killed, more than 70,000 injured and extensive damage in north Pakistan, in particular, the area of Muzaffarabad, Kashmir, where entire villages had been destroyed. The earthquake occurred along the collision boundary between Indian and Eurasian plates and this process of continent-continent collision originate important seismic and instrumental events in the area, such as the 1555 Kashmir earthquake (M>8) and the 1905 Kangra earthquake (Ms=7.8). In this work we describe the rupture process of the Pakistan earthquake estimated from teleseismic broad-band waveform. A finite fault inverse method has been used to carry out the slip distribution on the fault. For the inversion

we selected and analysed 28 vertical broad-band wavefroms. They were bandpassed between 0.002–0.5 Hz, and converted to ground displacement with a sampling rate of 1 Hz. Fault orientation and its dimensions are fixed on the basis of CMT inversion results and the aftershocks distribution. Results indicate reverse faulting on a NW/SE striking fault with dip-slip motion and a bilateral rupture propagation (vr=2.7 km/s). All seismic moment was released on a single asperity with very large slip near the surface. The process has a duration of 40s and the seismic moment obtained is 2.7x1020Nm (Mw=7.6).

Contacts: jborges@uevora.pt

## SEISMIC MOMENT TENSOR FROM REGIONAL RECORDS: FAULT PLANE SOLUTION VS. NON-DOUBLE-COUPLE MECHANISM DISTORTION – ID 1806

*J. Sileny, Geophys. Inst. Czech Acad. Sci., Czech Republic*
*Z. Jechumtalova, Geophys. Inst. Czech Acad. Sci., Czech Republic*

Regional moment tensors (RMT), routinely determined for moderate earthquakes by several agencies, have the capacity to describe a general dipole source. Apart from the double-couple (DC), equivalent to a shear slip along a planar fault in an isotropic medium, more complex types of faulting expressed in non-DC source components are included as well. Alternatively, non-DC mechanism can be a consequence of a shear slip embedded in an anisotropic medium. Resolution of RMTs is basically limited by quality of the data and success in construction of the Green's function. The latter point demands for a good model of the crust, which is however rarely available in sufficient detail. We suggest a jack-knife estimate of the error in the RMT retrieval, which in numerical tests appears to be more appropriate and useful than the error constructed by perturbing the parameters of the model. The DC and non-DC part of the RMT is affected differently by noise contamination of regional seismograms and by mismodeling of the crust. The DC component of the source, i.e. a shear slip traditionally anticipated as an earthquake mechanism, is fairly robust. This means that the basic information on the mechanism of a tectonic earthquake – the fault plane solution (FPS) – is mostly correct. On the other hand, the non-DC source components are largely vulnerable to both a noise contamination and the earth crust mismodeling. As such, they are very unreliable if retrieved from regional records.

## SEISMIC SOURCE MECHANISM - RESOLUTION OF DC AND EXTRA-DC COMPONENTS – ID 1807

*J. Sileny, Geophysical Institute, Czech Acad. Sci., Czech Republic*
*A. Milev, CSIR Natural Resources and the Environment, South Africa*

Traditional assumption about a seismic source as a double couple (DC) can represent a serious limitation for describing mechanisms of mining induced seismic events. In mining conditions more general process than a shear slip can occur due to stress concentration on mined-out areas. We assume both non-DC components of the moment tensor (dipoles), and a single force. On the 5 seismic events recorded at a deep level gold mine in South Africa, we demonstrated that waveform modeling is not successful enough due to poor information about the medium. Inversion of amplitudes of direct P and S waves is more prospective thanks to their smaller sensitivity to details of the medium and possibility to correct them for ray bending and shear wave splitting prior to the inversion. Moreover, we are able to estimate the error of the resulting mechanism due to neglect of ray bending. All 5 events processed display extra-DC mechanisms which are significant at 95% considering the mismodeling of the rock-mass by a homogeneous isotropic medium. The mechanisms are mostly in agreement with the situation in the mine. One of them is a sub-vertical pressure single dipole complemented by an implosion, which is the body force equivalent of a collapsing horizontal crack or a burst of a pillar supporting the roof of a mined-out cavity. Two others are close to a pressure single couple, too. All of them are located on the pillars. One of the events is mostly DC accompanied by a compensated compressive dipole, which may be associated to nearly vertical dip-slip along a fault in the roof of a cavity. Its location on the margin of a wide pillar supports the interpretation. Alternatively, for 2 events a downward single force matches the data as well, but the events are too strong for a cavity collapse.

## TENSILE SOURCE COMPONENTS OF SWARM EVENTS IN WEST BOHEMIA, CENTRAL EUROPE, IN 2000 RETRIEVED BY CONSIDERING SEISMIC ANISOTROPY – ID 1808

*D. Roessler, University of Potsdam, Germany*
*F. Krueger, University of Potsdam, Germany*
*G. Ruempker, University of Frankfurt/Main, Germany*

Anisotropic elastic properties cause spurious non-double-couple moment tensor components of earthquakes. As a result moment tensors of earthquakes in anisotropic rocks may be difficult to interpret in terms of possible volumetric changes, i.e. the opening or closing of a crack during faulting. Although commonly observed in many regions of the earth, seismic anisotropy is usually neglected during source retrieval of earthquakes.

We use an inversion algorithm for the determination of properties of seismic point sources in inhomogeneous anisotropic media based on ray-theory computations. Together with the moment tensor we directly invert for the geometry of dislocation point sources. From the source geometry we derive the angle between the slip direction and the fault normal to describe tensile source components.

The algorithm is applied to 112 major swarm earthquakes (Ml>=1.7) from West Bohemia (Central Europe) that occurred during the last intense swarm episode in 2000. For source retrieval, we use dense seismic network data as well as different inhomogeneous anisotropic and isotropic velocity models. The obtained fault orientations dominantly show oblique normal faulting on a steep North-South trending fault. Depth-dependent dip variation occurs. For more than 60% of the events we find tensile components indicating volume increase during rupturing. The largest tensile components are observed during the earliest swarm phases and greater depth depth. Although the strike of the principle stress axes is consistent with the stress field in Central Europe, depth dependence in plunge of the P and the T axes is observed. Depths of changes in source properties coincide with model boundaries observed from seismic velocity and gravity modelling at about 8.4 km and 9.5 km. Our results support observations of event triggering due to pore pressure variations by migration of over-pressurised magmatic fluids from a reservoir below the earthquake foci.

## COMPARISON OF THE 1997 AND 2000 SWARMS IN WEST BOHEMIA (CENTRAL EUROPE) FROM VIEW-POINT OF THE LOCATION, SPACE-TIME ENERGY RELEASE AND SOURCE MECHANISMS – ID 1875

*J. Horalek, Geophysical Institute, Academy of Sciences, Czech Republic*
*T. Fischer, Geophysical Institute, Academy of Sciences, Czech Republic*
*J. Sileny, Geophysical Institute, Academy of Sciences, Czech Republic*

One of apparent geodynamic features of the western part of the Bohemian Massif is periodically reoccurring intraplate earthquake swarms, mostly of magnitude ML $<$ 3.5 at focal depths below 4 km. The Nový Kostel (NK) focal zone dominates the recent seismicity. The NK zone shows a distinct planar character; most of earthquake foci are located at depths between 6 and 11 km at a steeply dipping main fault plane (MFP). Two recent larger swarms, which occurred there in January 1997 (nearly 600 ML$\leq$ 3.0 events) and in September to December 2000 (about 20 000 ML $\leq$ 3.4 events), were located about 1 km apart. Both swarms evinced strong time and space clustering, i.e. short inter-event times and narrow focal volumes. Nevertheless, the swarms manifest numerous significant dissimilarities that imply their different evolution. The 2000-swarm consisting of nine distinctly separated phases was wholly located at the MFP, whereas that of 1997 was of the two-phase character and took place in the two-arm cluster

located across the MFP. Source mechanisms (in the moment tensor description) also noticeably differ. Those of the 2000 swarm are cognate and show oblique normal or strike-slip faulting, whereas during the 1997-swarm two different mechanisms occurred: oblique normal faulting with a pure double-couple source (during the 1st swarm phase) and oblique thrust faulting with non-double-couple source (during the 2nd swarm phase). Space and time distribution of the consecutive 2000-swarm events indicates a relevance of triggering effect of the prior earthquake upon subsequent events that makes for the self-organization of the swarm activity, while the space-time development of the 1997-swarm is indicative of presence of the high-pressured crustal fluids, which could bring the fault close to its critical state and thus facilitated origination of the oblique thrust, non-DC events in the 2nd phase of the swarm.

### REGIONAL MOMENT TENSOR SOLUTIONS IN THE GULF OF SIGACIK -NE AEGEAN REGION- NEW FINDINGS FOR THE GULBAHCE FAULT – ID 1962

*N. Meral Ozel, Kandilli Obs.&ERI Bogazici Univ., Turkey*
*M. Yilmazer, Kandilli Obs.&ERI Bogazici Univ., Turkey*
*A. Berberoglu, Kandilli Observatory & ERI, Bogazici Univ., Turkey*

We have applied regional moment tensor inversion to regional waveforms of recent earthquakes from the NE Aegean Region and obtained fault mechanism solutions for thirty-eight events. The earthquakes sequence in the Sigacik-NE Aegean Region (Ml=5.7, 5.8 and 5.9) and their aftershocks occurring within the period 17 October to 30 November, 2005 were recorded by recently installed broad band seismic stations of Kandilli and enabled the analysis of their fault mechanisms. The analysis of these regional earthquakes provides useful information to better characterize the geology and seismotectonics of the Gulbahce fault. It should be noted that most of the moderate-size earthquakes recorded in this region did not rupture the surface, thus, their source mechanisms solutions provide essential information for the association of the activity with mapped faults and possibly help identification of unknown parameters of Gulbahce faults. The Regional Moment Tensor (RMT) inversion was performed in three frequency bands, which depend on the magnitude of the event; ranging from periods 10-30 sec for $3.6<M<4.5$, through 20-50 sec for $4.5<M<5$ and 20-100 sec for $M>5$, up to the window 50-200 sec for the largest events occurring in the region. One of the nodal planes is striking NW-SE and the other shows east-northeast strike with normal mechanisms. This earthquake activity was observed in the southern margin of the Gulbahce fault, around Sigacik bay in a region considered to be under N-S extension as a response to the westward motion of Anatolian block. Majority of the events of this sequence show strike slip with an oblique component. The observed solutions, showing NE-SW oriented strike-slip faulting, are in agreement with the bathymetric and the multi-channel seismic surveys conducted in this region. The 38 ($M>3.4$) aftershocks occurring in this region also show excellent lineation along a NE-SW trend which agrees well with the strike-slip focal mechanisms determined by this study.

### THE 2000-EARTHQUAKE SWARM IN THE WESTERN PART OF THE BOHEMIAN MASSIF (CENTRAL EUROPE): DOUBLE COUPLE VS. NON-DOUBLE-COUPLE EVENTS – ID 2034

*J. Horalek, Geophysical Institute, Academy of Sciences, Czech Republic*
*J. Silený, Geophysical Institute, Academy of Sciences, Czech Republic*
*Z. Hudová, Geophysical Institute, Academy of Sciences, Czech Republic*

Periodically reoccurring intraplate earthquake swarms, mostly of magnitude ML $< 3.5$, are one of the geodynamic features of the western part of the Bohemian Massif. The last swarm, which occurred there between August and December 2000, consisted of about 20 000 ML $\leq 3.4$ events. All the foci were located at a circular fault plane of a 3 km diameter at depths between 7.5 and 10.5 km, and showed a pronounced migration along the fault plane. The swarm was recorded by 5 to 16 well distributed local stations and located using the master-event method with accuracy better than 150m. Source mechanisms in the full moment tensor description (MT) were retrieved for more than 60 events. We employed a single-source, absolute-moment tensor inversion, which inverts body-wave peak amplitudes using synthetic Green functions (GFs). To avoid difficulties with the S-wave amplitudes due to post-critical incidence we inverted only direct P- and SH-wave amplitudes. The fault plane was divided into segments of 400m x 400m. For each segment we calculated respective GFs and retrieved MTs of at least two events. The solutions prove that synthetic amplitudes fit those extracted from seismograms very well, particularly the P-wave amplitudes. Numerous MTs exhibit significant of double-couple components, mainly compensated linear-vector dipole. Space and time distribution of the MTs signifies in fact a scenario of the swarm evolution. Furthermore, considerable P and S-wave amplitudes allowed us to test stability of the MT solution, particularly of non-double-couple components. The aim of this contribution is (1) to demonstrate faulting processes acting during the swarm, particularly a progressive propagation of the rupture, and (2) to point out causes that can yield fictitious non-double-couple parts in MTs even though RMS of the real and synthetic amplitude differences, as a measure the of the successfulness of the MT solution, is sufficiently small.

## SC-C 1: Earthquake Source Complexity: From Geology Through Kinematic and Dynamic Models to Realistic Ground Motion Simulations

Level 2

### PREDICTION OF NEAR-FIELD STRONG GROUND MOTIONS FOR A SCENARIO EARTHQUAKE ON AN ACTIVE FAULT – ID 19

*W. Haiyun, Harbin Institute of Technology, China*

A method to predict near-fault strong ground motions for a scenario earthquake on an active fault was proposed. Firstly, macro-source parameters characterized the entire source area, i.e. global source parameters, such as fault length, fault width, rupture area, average slip on the fault plane, were estimated by seismogeology survey, seismicity and seismic scaling laws. Secondly, slip distribution characterized fault heterogeneity or roughness, i.e. local source parameters, were reproduced by hybrid slip model. Lastly, the finite fault source model predicted by mentioned-above was combined with stochastically synthetic technique of ground motion using dynamic corner frequency based on seismology. Acceleration time histories on the three stations during 1994 Northridge earthquake were predicted, And comparison between predicted and recorded acceleration time histories show that the method is doable and applied.

### COSEISMIC DEFORMATION OF THE AL-HOCEIMA 2004/02/24 EARTHQUAKE FROM INSAR, GPS, SPOT AND FIELD DATA – ID 900

*A. Tahayt, Abdelmalek Essaadi University, Morocco*

A. Tahayt, K. L. Feigl, A. Fadil, E. Berthier, F. Gomez, T. Mourabit, B. Brooks, Ph. Vernant, L. Dorbath, L. Rivera, S. Chevrot, J. M. Davila, D. Ben Sari, M. Serroukh , R. Reilinger, and J. Van der Woerd

On 24 February 2004, a magnitude 6.4 earthquake struck the Al-Hoceima region (Morocco) causing 629 fatalities. This earthquake, like a similar event in 1994, is the result of the ongoing, oblique collision between Africa and Eurasia. The complexity of the collision process in this region is illustrated by the occurrence of extension, roughly in the same direction as the Africa-Eurasia convergence, oblique strike-slip faulting onshore and within the Alboran Sea. The location, focal mechanism, and aftershocks

of these events can help to define the present day kinematics of this complex plate boundary zone. Here, we combine the data from three accurate satellite geodetic systems (ENVISAT, GPS and SPOT) to study the Al-Hoceima event and its aftershocks. Two interferograms generated from descending and ascending ENVISAT satellite radar images record two components of the coseismic displacement field. In addition we measured co-seismic displacement vectors at several GPS sites. The correlation of two 2.5 meter resolution SPOT-5 images shows that the horizontal slip along the surface rupture due to this earthquake must be smaller than the measurement uncertainty, of the order of half a meter. Although some minor surface crackings were observed in the field, their small vertical throw (decimeter), lack of horizontal throw, short length ( 2 km) and valley-parallel strike suggest that they are secondary features. By combining these data with elastic dislocation models, we consider the two possible rupture planes that strike NNE-SSW and WNW-ESE. Our interpretation suggests that the collisional strains in the southern part of the boundary zone are mostly accommodated in the northern Rif Mountains and the Alboran microplate.

### RUPTURE ANALYSIS OF DECEMBER 10, 2003 CHENGKUNG, TAIWAN EARTHQUAKE (MW 6.5) BASED ON TELESEISMIC AND STRONG-MOTION DATA SETS – ID 1742

*G. Orgulu, Bosphorous Univ., Kandilli Observatory and E.R.I., Turkey*
*S. Yolsal, Istanbul Technical Univ., Department of Geophysics, Turkey*
*T. Taymaz, Istanbul Technical Univ., Department of Geophysics, Turkey*
*M. Aktar, Bosphorous Univ., Kandilli Observatory and E.R.I., Turkey*
*B. S. Huang, Academia Sinica, Institute of Earth Sciences, Taiwan*

With different data sets of teleseismic and strong-motion we analyze slip distribution of Chengkung earthquake (Mw 6.5, BATS) that occurred on 10 December 2003 (04:38:13.5, UTC) near a coastal town of Chengkung in eastern Taiwan. The epicenter is located at 23.066 N and 121.398 E with a source depth of 18 km (CWB). The earthquake ruptured Chihshang fault which is a thrust fault trending in NNE direction and dipping to southeast. This information of the casual fault is inferred from field observations of numerous cracks or fissures near the surface trace of the Chihshang fault. This faulting draws attention of earthquake scientists due to its position as a part of plate boundary between the Philippine Sea and Eurasian plates and due to its seismotectonic behavior revealing with a creep. At the same time this event has another striking feature due to a fan-shaped pattern of co-seismic displacements since its focal mechanism solution indicates almost a pure thrust faulting. The fault plane that we envisaged for this event is defined with a strike of 23, a dip of 42 and an average rake of 75 based on focal mechanism solutions reported by different agencies (HRV, USGS and BATS). Preliminary slip models produced for teleseismic data consisting of 35 broadband stations indicate that the rupture mechanism for this event appears with two slip patches. Prevailing slip patch nucleated near the earthquake hypocenter and then propagated to the SSW part of the rupture plane. The second patch is also appearing at SSW part, but at a shallower depth relative to the first patch. This result may answer questions like "why maximum ground-motion displacements are observed at some strong-motion stations to the southwest of the earthquake epicenter?" Further findings of slip models and rupture mechanisms will also be discussed.

### RUPTURE AT STRIKE-SLIP FAULTS - RESULTS OF NUMERICAL MODELLING AT PLANAR AND INCLINED FAULT SEGMENTS – ID 1769

*H. Schelle, GeoForschungsZentrum Potsdam, Germany*
*G. Grünthal, GeoforschungsZentrumPotsdam, Germany*

Strike-slip faults are commonly characterized by changes in strike and dip on a variety of scales. In particular faults with strike changes in a kilometre-scale can rupture in individual earthquakes with meters of offset. Models of strike slip faults without and with a bend were investigated numerically with the three-dimensional distinct element code 3DEC. Tectonic loading, stress accumulation, subsequent failure with stress transfer, and the recurrence of these processes were simulated. A Mohr-Coulomb slip model with stick-slip behaviour was used for the loaded fault segments. Repeated failure processes are simulated since an instantaneous healing process was introduced. The loaded segments themselves were embedded in a sliding fault surrounding. The generated earthquake sequences possess the characteristic features of real earthquake catalogues, such as magnitude-frequency distributions according to the Gutenberg-Richter law, significantly varying temporal occurrence of main events, and foreshock-aftershock distributions. The spatio-temporal distribution of large events were especially analysed. The simulated earthquake sequences were used to calculate the long-term time-dependent probability of the next large earthquake on the distinct fault segments. The distribution of the inter-event times were fitted to several well-known statisti-cal distributions. The differences of these fits are discussed with respect to the distinct distributions. Further, the possibility of cascading (i.e. the rupture of focal segments immediately one after the other) is investigated.

### THE SAORGE-TAGGIA LINE, WESTERN LIGURIA (ITALY): MULTIDISCIPLINARY ANALYSIS OF A COMPLEX FAULT SYSTEM – ID 1827

*C. Turino, Università degli Studi di Genova, Italy*
*D. Scafidi, Università degli Studi di Genova, Italy*
*E. Eva, INGV, Italy*
*S. Solarino, INGV, Italy*

In this contribution we show as studies based on combined seismological and geological investigations result in a better knowledge of a seismogenic structure and give hints on its mechanism of rupture. The Saorge – Taggia line, western Liguria, is a system of strike slip faults with NW – SE orientation. It extends from the coast inward up to a northern limit , the Breil-Sospel-Monaco fault, a NE-SW strike slip structure. The structure shows a remarkable geological complexity and a diffuse seismicity which confirms its active character. In the past, some significant earthquakes were later associated to the Saorge-Taggia system, causing a growing interest on the structure leading to a seismic monitoring performed on both sides of the French-Italian border. Such a concentration of seismic stations enables to reveal, record and localize earthquakes with very low magnitude threshold and with error in the determination of hypocentral parameters extremely contained. This enables the ideal conditions for the application of detailed seismological investigations. We present, in a preliminary form, the combined results of techniques to determine shape and deep extension of seismic lineations (seismic tomography), the precise position of hypocenters and the fault mechanisms. They suggest that the strike slip nature of the structure is not equally spread but turns to a more transtensive component in the northern part of the system; the seismicity is less evident in the south termination of the fault, but it may be masked by anthropic activities and sedimentary thickness. Finally, a comparison between historical and current seismic activity seems to evidence that the fault alternates period of low magnitude, frequent events with medium to strong, isolated episodes. The likely interaction with the surrounding and cutting lineations makes hypothesis on the nature of this kind of energy release uncertain.

### IMAGING OF SEISMIC RUPTURE PROCESS OF THE CYTHERA M6.7 EARTHQUAKE (JANUARY 8, 2006): INVERSION FROM THE RELATIVE SOURCE TIME FUNCTIONS. – ID 1877

*V. Plicka, Charles University in Prague, Faculty of Mathemati, Czech Republic*

On January 8, 2006 at 11:34 UTC a strong earthquake of 6.7 magnitude occurred near the island of Kythira, about 200km south of Athens. The shocks have been felt in regions, far from

the epicentre (Italy, Croatia, Bosnia-Herzogovina, Malta, Egypt and Israel), fortunately there were no reports of injuries. Our interest is to describe, very fast, the basic characteristics of the finite extent fault. Slip patch method (Vallée and Bouchon, 2004) is very powerful and fast method to find the second-order kinematic parameters of the source. The source model of the earthquake is described by 1 or 2 slip patches (ellipses) with constant value of the slip for each patch. This simplification keeps the physical meaning of the extended source and moreover, makes source inversion more robust, because a few parameters are searched (slip value, the position and size of the ellipses, rupture velocity). Two individual source pulses of apparent source time functions (STFs) obtained by empirical Green's function method, clearly indicate, that source is complex, with two main asperities. STFs were used as input data in non-linear inversion by neighborhood algorithm (Sambridge, 1999). The results confirm that the fault is composed from two asperities with average slip of 2 metres. The regional broad-band waveform data of the mainshock and aftershock from five stations are obtained from international data center GEOPHON.

### A NEW KINEMATIC SOURCE INVERSION SCHEME – ID 1878

*J. Burjanek, Charles University, Faculty of Math. & Phys., Czech Republic*
*J. Zahradnik, Charles University, Faculty of Math. & Phys., Czech Republic*

We present a kinematic finite extent source inversion scheme, introducing an innovative parametrization of the problem. Particularly, we assume a spatial slip distribution composed of overlapping 2D Gaussian functions on regular grid. Temporal evolution of slip is described with prescribed slip velocity function, with free rupture velocity and rise time parameters. Fixing the values of rupture velocity and rise time for whole fault makes the problem linear in static slip. The inversion algorithm works as follows. At first we fix rise time and rupture velocity and calculate seismograms for each Gaussian function separately. Then a linear inversion is performed to get optimal weights (=amplitudes) of these Gaussian functions. Such procedure is done for a number of rupture velocities and rise times, optimal values of these are obtained by simple grid search. L2 norm is used as an objective function. The linear inversion for static slip is done with positivity constraint, so called 'Quadratic programming' was applied to solve such problem. Our method benefits from simplicity of linear problems and favourable spectral properties of Gaussian function. The latter prevent from employment of artificial smoothing operators. Thus a direct insight into spectral properties of the static slip distribution of real earthquakes is obtained. The method has passed successfully 'Blind test for kinematic source inversion' within EU SPICE project and has been further applied to the 2000 M6.6 Western Tottori, Japan, earthquake.

### POST SEISMIC MULTIPARAMETER STUDIES TO IDENTIFY SEISMOGENIC STRUCTURES IN FAULT PLANE AREAS – ID 1902

*M. Sobiesiak, GFZ, Germany*

Multiparameter studies of aftershock sequences can constrain the heterogeneous structure of active faults and hence, help to identify seismogenic structures (asperities)in fault plane areas.

We used the spatial distribution of the seismic b-value in combination with teleseismic source time functions to identify areas of largest coseismic moment release, stress drop and slip and estimated the respective values for these source parameters.

Positive correlations to other geophysical parameters like isostatic residual anomalies, radiated seismic energy or the spatial distribution of seismic velocities were able to support location and extent of the seismogenic features.

In the case studies which will be presented, strikingly good correlations to geologic and tectonic settings could be found. This consistency between areas of high moment release for example and changes in material properties along the fault plane, helped to obtain new ideas about the nature of seismogenic structures.

If geology is involved in the generation of asperities, this employs long term steady state conditions and yield the hypothesis that they might be capable to survive several seismic cycles.

## SC-C 2: Recent Developments in Theoretical and Numerical Earthquake Source Dynamics: New Horizons to Predict Seismic Radiation and Near-Field Ground Motions

Level 2

### THE CHAOS THEORY IN FRACTAL GENERATION OF SYNTHETIC EARTHQUAKES – ID 671

*R. Magaña, Instituto de Ingenieria, UNAM, Mexico*
*A. Hermosillo, Instituto de Ingenieria, UNAM, Mexico*
*M. Romo, Instituto de Ingenieria, UNAM, Mexico*
*M. Pérez, ENEP, Aragón, Mexico*

In this work the relation among the non-linear dynamic behavior of complex systems and the algorithms for fractal generation of synthetic earthquakes is analyzed. That is to say the relationship among the algorithms generated by means of fractal procedures and the non-linear sets of equations (that model the vibration of the terrestrial bark), is settled, where it is take into account the geometric characteristics of the present stratigraphy in a site, as well as of the mechanical behavior of the present materials. So with that, the fractal algorithms are based on the physical characteristics of the modeled system. Everything will be necessary to understand the behavior observed in different sites, considering the site geology. In synthesis the content of this work consist on the following: a) concepts of the chaos theory, b) different systems where it is applied (physical, biological, etc), c) deterministics mathematical models that reveal chaotic behavior, d) relationship with the fractal algorithms that provide graphic representations, e) its implications in the interpretation of real accelerograms, and f) its relationship with the previous works of the authors (about an neuro-fractal algorithm for earthquake simulation).

### SOURCE TOMOGRAPHY OF MINING-INDUCED SEISMIC EVENTS AT "RUDNA" COPPER MINE – ID 1641

*G. Kwiatek, Institute of Geophysics, PAS, Poland*
*W. Debski, Institute of Geophysics, PAS, Poland*

The kinematic rupture process of the three, small, mining-induced seismic events (Mw 2.9-3.0), which occurred at "Rudna" and "Polkowice-Sieroszowice" copper mine in Poland are studied in details. Seismograms of selected events were recorded by the set of over 60 vertical, short-period seismometers, located within a distance up to 15km from the epicenter, mainly at the exploitation level. Inversion of recorded seismograms for the rupture slip history was carried out in two steps. Firstly, the relative source-time functions (RSTF) were calculated for each station using the empirical Green's function technique. The pseudo-spectral approximation of the sought RTSFs by the finite sum of Gaussian kernel functions with variable magnitudes and time shift, as well as the adaptive simulated annealing optimization was used in order to improve the stability of the deconvolution procedure. Next, the RSTF functions were inverted for the kinematic, space-time history of the rupture, using the classical simulated annealing optimization scheme. The spatial orientation of the rupture planes were determined by the moment tensor inversion and the result of the spectral analysis were taken as the a priori constraints of the source sizes (100m x 100m). For the tomography purpose the ruptured part of the fault planes were divided into 25 or 49 – equal-size patches, depending on resolution of the data and additional spatial resolution tests. The Haskell-like source model with a unilaterally propagating, constant rupture velocity rupture was assumed as the a priori model. At both inversion stages the inversion uncertainties were estimated

by means of the Markov Chain Monte Carlo sampling technique. The obtained results indicate a spatio-temporal complexity of mine induced seismic events moment release.

### DYNAMIC SIMULATION OF A DIPPING FAULT USING A 3D FINITE DIFFERENCE METHOD WITH NONUNIFORM GRID SPACING – ID 1783

*Z. Wenbo, Lab of Computational Geodynamics, GUCAS, China*
*I. Tomotaka, DPRI,Kyoto Univ., Japan*
*I. Kojiro, DPRI,Kyoto Univ., Japan*

We propose a method to analyze dynamic rupture processes of earthquakes with a dipping fault, using a 3D finite-difference (FD) method with nonuniform grid spacing. This approach does not require aligning the fault plane to the FD grid for implementation of the FD method. It can be used to deal with a realistically complex fault geometry model. We validate our method by studying two dynamic source problems that have been analyzed by Madariaga et al. (1998). One is the instantaneous rupture of a circular fault embedded in a homogeneous elastic medium; the other is the spontaneous rupture of a rectangular fault which starts from a local circular asperity on the fault plane. Our numerical results for different dipping faults are similar with those obtained by Madariaga et al. (1998) using a horizontal fault plane model in full space, thus, validating our method for dipping fault models. We apply the proposed approach to analyze the dynamic source process of the 2003 Tokachi-Oki, Japan, earthquake. The fault model of this earthquake is a dipping fault with a dip angle about 18-degree. We rebuild the dynamic rupture process of this event and simulate the near source strong ground motions based on the dynamic source model.

### SIMILARITY CHARACTERIZATION OF SHORT-TERM AFTERSHOCKS GENERATED BY THE FEBRUARY 11TH 2004, NORTHERN DEAD SEA (ML 5.1) EARTHQUAKE. – ID 1796

*G. H. Wust-Bloch, Tel Aviv University, Israel*
*M. Joswig, Universität Stuttgart, Germany*

Five hours after the February 11th 2004, Northern Dead Sea Earthquake (ML 5.1), nanoseismic monitoring (Joswig, 2005; http://www.geophys.uni-stuttgart.de/sss05.html) was applied to record a series of aftershocks. Within 17 hours, a series of 61 aftershocks (-2.0 < ML < 2.4) were located and selected for similarity characterization. The non-random statistic distribution of these events shows a specific propagation pattern whereby the eight strongest (ML > 1.5) events are each followed by a series of decaying-magnitude events. Event series were characterized by similarity analysis based on waveforms. Each series shows high similarity but waveforms differ from series to series. Master event relocation provides related spatial clustering.

### USING THE RECURRENT METHOD FOR SEISMOLOGY PROBLEMS – ID 1823

*D. Malytskyy, Carpathian Branch of Subbotin Institute of Geophys, Ukraine*
*R. Pak, Carpathian Branch of Subbotin Institute of Geophys, Ukraine*
*O. Mujla, Carpathian Branch of Subbotin Institute of Geophys, Ukraine*

Studying spectral and dynamic parameters of earthquake sources is an essential condition to solve many problems of seismology. Physical properties of a medium as a function of stress must be studied in order to understand physical processes run near the source A method of solving direct problems is proposed and presented in the form of recurrent relationships. The equations obtained are suitable for numerical calculations. We obtain the exact solution for free surface displacements generated from a point source in a layered medium. In general earthquake sources are introduced by seismic moment tensor. We use the Bessel – Laplace transform for displacement potentials from which the displacements follow by spatial differentiation. The components of the seismic moment tensor are a function of time. It should be noted that wave field values on a free surface are obtained as strict recurrent analytical relations.

## SC-E 6: Earthquake Physics - Field and Laboratory Study

Level 2

### MAPS OF ALLOCATED ZONES OF TIDAL EARTHQUAKES IN KAMCHATKA (RUSSIA) – ID 730

*V. Saltykov, Kamchatkan Branch, Geophysical Survey, RAS, Russian Federation*
*Y. Kugaenko, Kamchatkan Branch, Geophysical Survey, RAS, Russian Federation*

We think that the Earth tides can not induce the earthquakes themselves, but ones can exert trigger influence on future source formed by more powerful tectonic processes. Then this influence can be manifested during long time of large earthquake preparation (Saltykov et al., 2004), and small earthquakes of this area will become an object of the tidal influence. Note: these small earthquakes are not foreshocks, this is background seismicity. The technique and the results of the search of such effects are presented. The influence of the Earth tides upon earthquakes with magnitude M>2.5 is investigated. Proposed technique of detection of tidal effects in seismicity allows finding in time and space anomalous zones corresponding to influence of separate tidal waves or tidal wave groups. The statistical significance of the anomalies is tested by method Monte-Carlo. This technique was approved on the catalogue of the Kamchatkan earthquakes 1962-2005. The maps of tidal earthquakes zones designed for whole Kamchatkan seismoactive area during different time interval from 1year to 40 years are presented. It is shown that for short time interval (3 years, 2003-2005) tidal zones are close to sources of large earthquake with magnitude M=6.7-6.9 (2003, Jun.16; 2003, Dec.5; 2004, Jun.10). Some modern zones having high statistical significance can not be connected with large earthquakes, but they are close to area, which marked by different scientists as large earthquake preparation area. For long interval (40 years) zones corresponding to different tidal waves influence have different tendencies in the spatial grouping. It is suggested that this difference can be explained by selectivity of trigger effect in earthquakes for different tidal waves, which is connected with variations in stress state of the medium. This research is supported by RFBR Grant 05-05-64276a.

### THE STRUCTURE OF THE CHUYA EARTHQUAKE (2003 SEPTEMBER, M=7.3) AFTERSHOCK PROCESS BY FOCAL MECHANISMS – ID 1226

*E. Leskova, Institute of Geophysics SB RAS, Russian Federation*
*A. Emanov, Institute of Geophysics SB RAS, Russian Federation*
*S. Goldin, Institute of Geophysics SB RAS, Russian Federation*

Earthquakes locations methods used in Altai-Sayan region till now are designed for a scarce network of regional observations. The deployment of a denser network of the Altai seismological test site made it possible to use other methods allowing more accurate solutions from local data. Chuya Earthquake (Gorny Altay, Russia, 27 September 2003, MS=7.3) occurred in the centre of Altay seismological test site. Using the seismological data of Altay seismological test site and epicentral field studies we attempt to make more detailed structure of Chuya Earthquake aftershock process. In this work we present analysis results of focal mechanism catalog of Chuya Earthquake aftershocks. Analysis was made at focal mechanisms attitude position and at parameters of principal stress axes. It is showed that along the fault line of Severo-Chuiskiy mountain range the focal mechanisms demonstrate an almost horizontal shift, while they change on the ends of the

seismic activation zone and the vertical component of this shift becomes essential. Preferred orientation of principal stress axes was discovered: it is submeridional to pressure axes and it is sublatitudinal to tension axes.

### SPATIO-TEMPORAL FEATURES OF SEISMICITY OF THE ALTAI-SAYAN REGION – ID 1231

*A. Emanov, Geophysical Survey SB RAS, Russian Federation*
*A. Emanov, Institute of Geophisics SB RAS, Russian Federation*
*A. Filina, Geophysical Survey SB RAS, Russian Federation*
*E. Leskova, Institute of Geophisics SB RAS, Russian Federation*
*Y. Kolesnikov, Institute of Geophisics SB RAS, Russian Federation*

Seismicity of the Altai-Sayan Mountain Region is analyzed along with the relief and active faults. It is found that in the most tectonically active structure seismicity occurs during the whole year and its pattern is stable from year to year. Geological structures are hierarchically organized by the rate of seismic events. The largest earthquakes in the region correlate with certain structures where active low-energy earthquakes occur. In the seismic mode we distinguish background seismicity and multiple seismic activation. Background seismicity that might appear at first glance to be chaotic is localized with time according with to the block structure of Altai-Sayan Mountain Region. The combination of elevated rock masses and depressions makes up a cellular structure that offers a resistance to collision with the Jungarian Basin. Background seismicity is concentrated mainly in the mountain chains around depressions. Seismic activation is considered as a nonstationary mode of one or other geological structure. Activation is closely related to the largest earthquakes; for the most part it proceeds as an aftershock process. Strong activation of the Altai and Sayan structures has specific scenarios of its development. Activation that has begun at the Businogol earthquake, December 27, 1991 (MS=6.5) and continues to date has a very distinctive character. This event can be related to the interface between the Altai-Sayan region and Baikal rift zone, where collision pushes the depression, while rifting tends to tear it apart. The opposition of the two forces gives rise to intermittent and long seismic activation.

### ANALYSIS OF THE STRESS STATE OF THE CHUYSKY 2003 EARTHQUAKE ZONE FROM SEISMIC TOMOGRAPHY AND SPACE PHOTOLINEAMENTS DATA – ID 1726

*I. Sanina, Institute of Geospheres Dynamics, Russian Federation*
*O. Usoltseva, Institute of Geospheres Dynamics, Russian Federation*
*G. Ivanchenko, Institute of Geospheres Dynamics, Russian Federation*
*A. Emanov, Institute of Geophysics, Russian Federation*

One of the recent concepts of earthquakes mechanisms (S.V.Goldin) assumes that the earthquake preparation process is the result of stress changes in a large volume of geophysical media surrounding the focus, while instability develops locally in a restricted area. To verify this hypotesis, a joint analysis of tomography and space photolineament data was carried out in the zone of the Chuysky, 27.09.03, earthquake, for the period before and after the event. The epicentral zone of the Chuysky earthquake is situated in the southern part of the Russian Altay. The density of automatically detected by LESSA program small photolineaments of W-N-W direction was analyzed for Chuyskaya depression region. The density distribution is well structured. Local maximums are connected with elongated linear zones partly included in regional Kuraysky shear zone. Most intensive local maxima are connected with the fracture zones joints. Summary density space-field of W and N-W direction photolineaments is formed by lineaments of thrust and shear-thrust kinematics mainly. These lineaments are elongated generally orthogonal to main tension regional stress direction. We detect Chagan-Usunsky block of high density of W and N-W directions by small automatically detected photolineaments. The area of newly-formed fractures Chuysky earthquake is placed on the border part of Chagan-Usunsky block. This area is cut in its eastern part from Chuysky depression by the set of automatically detected sub-parallel N-E lineaments. Kuraysky fracture zone and N-E shear zone are the main block-forming structures in western part of Chuyskaya depression. Regional contemporary formed block structure controls space distribution of earthquakes generation zones. Comparison of the distribution of lineament zones with seismic tomography results shows that the lineaments are traced to the depth of 19-25 km and their position coincides with the boundaries of blocks with sharp velocity variations.

## SC-F 0: Engineering Seismology (Open Session – Posters Only)

Level 2

### DEVELOPMENT OF ENGINEERING SEISMOLOGY IN CHINA – ID 182

*Y. Hu, Institute of Geophysics, China*

In China, earthquake engineering and engineering seismology started in the middle of 1950s and the main achievements in the field of engineering seismology are presented in this paper in six sections as follows. 1. Engineers working in the field of engineering seismology are not satisfied with the term earthquake magnitude, but prefer the ground motion parameters. The term earthquake intensity has been used in China before 2000, and our current zonation maps are in terms of ground motion parameters. One in effective peak acceleration a/g and the other in term of effective peak velocity v or the characteristic period Tg= $2\pi$v/a. 2. Ground motion simulated to match given response spectrum is required in China in the analysis of nuclear power plants or other important structures. A method has been given to generate time histories to match a given spectrum with errors much less than that allowed in the current seismic design code. 3. Our 2000 ground motion zonation maps consider some saturated design acceleration at short periods near epicentral regions, but the longer period spectra keep on increasing with both magnitude and distance. 4. Uncertainty in seismic regionalization is considered in the 2000 zonation maps. 5. Two kinds of site effects were considered in the 1964 model code in China: the ground failure of weak sites and the modification of the design ground motion by increasing those components closer to the natural periods of vibration of the soft site. This consideration in seismic design code is the early one in the world, roughly 30 years before the Japan code and USA code.

### SEISMIC CHARACTERIZATION OF THE BUILDING STOCK IN PONTA DELGADA : A FIRST ATTEMPT – ID 323

*P. Silvestre, Centro de Geofísica da Univ. de Lisboa, Portugal*
*P. Teves-Costa, Centro de Geofísica da Univ. de Lisboa, Portugal*

The Azores archipelago is located near the triple point of the American plate, the Eurasian plate and the African plate, in the North Atlantic Ocean. Due to this particular location it is the Portuguese region which presents the higher level of seismic hazard. In the aim of the research project COMICO (Contribution to Seismic Risk Mitigation for Ponta Delgada, Angra do Heroísmo and Horta Towns), ambient vibration measurements were performed on 17 buildings in the town of Ponta Delgada. The studied buildings can be divided in two main categories, according to the materials used for their construction: masonry and reinforced concrete. In general, these buildings are not isolated, but are part of a block. The number of stories of the studied buildings varies from 2 to 21. The data was processed in accordance with the methodology proposed by Nakamura (1989; 2000), using the JSesame program (Sesame, WP03 Team, 2003) to calculate the H/V, EW/V and NS/V spectral ratios, and also using the Geopsy software to analyse the individual spectra and to calculate the damping. The fundamental frequencies of the buildings, in the transverse (EW) and longitudinal (NS) directions, were determined. These values vary between 1.4 Hz and 7.8 Hz; the damping varies from 1.0%

and 5.6%. It was observed that, in general, the natural frequency and the damping decrease as the number of stories increases. The natural frequency of the ground was also calculated, in order to check potential resonance effects. Following the methodology developed in Risk-UE, with some adaptation, we estimated the vulnerability curves for the different studied typologies. This is still a tentative methodology and other procedures will be developed, in the aim of the COMICO project, to better characterize the building seismic behaviour of Ponta Delgada.

### COMPARISON OF TWO ARRAY TECHNIQUES TO DETERMINE SOIL STRUCTURE FROM MICROTREMOR MEASUREMENTS – ID 341

*M. Rodriguez, Instituto de Ingenieria, UNAM, Mexico*
*F. J. Chavez-Garcia, Instituto de Ingenieria, UNAM, Mexico*

Prediction of site effects during earthquakes requires the determination of the site transfer function, or of its subsoil structure, from which a theoretical transfer function may be computed. A number of techniques have been devised to this end. The more popular ones are those based on microtremor records, due to the facility and low cost of the measurements involved, and because it does not require seismic sources, impossible to use in some environments. During the last decade, the main technique used has been that of H/V spectral ratios of noise measurements made with only one station, which provides an estimate of the site transfer function. However, the strong limitations of this technique have spurred the exploration of other methods. Two of them are ReMi, proposed by Louie (2001), and SPAC, proposed a long time ago by Aki (1957). Both, SPAC and ReMi, allow to obtain a phase velocity dispersion curve from array microtremor measurements, from which a velocity profile may be derived by inversion. Recent results (Chavez-Garcia et al., 2005) have shown that it is possible to use SPAC without the geometrical restriction on the shape of the array (according to Aki it should be a circle). In this paper, we present a comparison between the results obtained by SPAC and ReMi at a few sites in the state of Colima, Mexico. At two of the sites we are able to compare the results with velocity profiles measured in boreholes using a suspended log. Our results allow to infer some rules to know when SPAC or ReMi can be useful, and what are those parameters that need to be considered carefully before making any measurement. One interesting point is that the two methods can be used with the same dataset, thereby duplicating the value of each measurement.

### SEISMIC HAZARD OF THE CHNPP SITE IN UKRAINE – ID 357

*A. Kendzera, Institute of Geophysics of National Academy of Sci, Ukraine*
*V. Omelchenko, Institute of Geophysics of National Academy of Sci, Ukraine*

The study of seismic hazard in Ukraine in long time was linked only to the territories located in the so called seismically activated areas confined to the borders of tectonic plates, mountains and submontane trough. But on the East-European Craton (EEP) the origins of earthquakes are observed practically everywhere. On the platform part of Ukraine only a few perceptible local earthquakes are known. Their origins were located within the earth's crust. As a result the seismic effects had a local character. At the last Ternopil earthquake in some capital structures the cracks with a few centimetres width was appeared. Such phenomena confirm a common rule in obedience to which: the shallow earthquakes on platforms can cause destructive effects even at the low values of magnitude ($M \leq 4{,}5$). In this connection, at estimation of seismic situation of the large industrial objects located on the EEC, it's not impossible to not take into account the potential danger from local powerful seismic events and strong subcrust earthquakes from Vrancea zone. The purpose of report is to develop 10,000-year general response spectra for site-specific soil conditions for the Chernobyl New Safe Confinement Project in the Ukraine. With this purpose a seismic station equipped with wideband devices Guralp was installed close to the "Shelter". Additional field measurements were continuously maintained from September 8, 2004 till March 24, 2005. This allowed for successful registration of the Vrancea zone earthquakes directly at the ChNPP site. The records of the Vrancea and other strong teleseismic earthquakes were used for precise determining of design accelerograms and response spectra simulating the effect of maximal design earthquake from the Vrancea zone at the ChNPP site by accounting for a low-frequency effect, which was earlier impossible because the lack of objective data.

### STATISTICAL ESTIMATION OF SEISMIC HAZARD FOR STABLE CONTINENTAL REGIONS USING EXTREMAL MIXTURE DISTRIBUTION – ID 432

*K. Jaiswal, Indian Institute of Technology Bombay, India*
*R. Sinha, Indian Institute of Technology Bombay, India*

The application of finite mixture distribution in statistical analysis is frequently proposed as a combination of two normal, lognormal, or exponential distributions for mixed data samples. The theory of extremes has been applied successfully in the past for modeling the occurrence of maximum magnitude earthquakes within certain geographic region over prescribed period of past seismic activity. The theory works on the assumption that observations follow either Gumbel Type I or Type III distributions satisfying particular degree of confidence level in the form of goodness of fit test. The advantage of the method lies in the fact that it uses extreme events (largest) of definite time interval (i.e. say monthly or yearly) that are widely felt and well catalogued.

This paper proposes an alternative approach based on finite-mixture distributions whereby more realistic prediction of low probable events can be made which are of high engineering importance. The concept and basic relationships defining mixture distributions and the applicability has been discussed. Theoretical and analytical groundwork for the application of a finite mixture asymptotic distribution consisting of Type II and Type III distribution is developed. The model is applied to annual maximum earthquake magnitude occurrence in Peninsular region of India i.e., between 10-26 N and 68-90 E with the catalog data spanning over the period 1841-2002. The results are expressed in terms of exceedence probabilities and return period for various design level.

It has been concluded from the investigations that uncertainty in predicting low probable events can be reduced to large extent by modeling the magnitude occurrence of a region with more refined mixture models. The statistical approach proposed in this paper is useful in the case of seismic hazard assessment for regions with low to moderate seismicity and having small-recorded catalog data.

### IMPACT OF EPISTEMIC UNCERTAINTY ON SEISMIC HAZARD ESTIMATES – ID 560

*R. M. Musson, BGS, UK*

Epistemic uncertainty in seismic hazard is defined as uncertainty about things that have a true value which is unknown, contrasted with aleatory uncertainty, which is the uncertainty about things that are unknowable, because they pertain to random processes. One can imagine a situation where one has to estimate the number that will be rolled on an unknown number of dice. The person rolling the dice knows the number of dice, but for the estimator this is epistemic uncertainty. If the estimator were able to find out the number of dice, this epistemic uncertainty would be removed, but the actual number to be rolled could still not be predicted because of the irreducible aleatory nature of dice throws. Estimating fully the epistemic uncertainty in a seismic hazard model is considered to be important in order to express the uncertainty in the final hazard results (typically as a suite of percentile hazard curves). But what effect does epistemic uncertainty have on the actual value of the hazard results – specifically the value that will be carried through into the design process? Potentially, epistemic uncertainty could be symmetrical about the best estimate value in such a way that the overall impact is small. Some typical cases are examined.

## COMPARISON BETWEEN THE ITALIAN SEISMIC HAZARD MAP (PRSTN04) AND ALTERNATIVE PSHA ESTIMATES – ID 595

*M. Mucciarelli, University of Basilicata, Italy*
*D. Albarello, University of Siena, Italy*
*V. D'Amico, University of Siena, Italy*

A seismic hazard map (PRSTN04) has been recently produced as a base for the seismic zoning of the Italian municipalities. PRSTN04 is calculated over a regular grid for the whole territory of Italy and mapped as maximum acceleration (Amax) with a fixed probability of occurrence in a given period. We compare this map with an alternative one, produced using the site intensity approach estimating (Imax). We estimated the maximum Intensity (Imax) with a fixed probability of occurrence in a given period for the sites with more than 5 intensity values corresponding to documented local effects during past earthquakes. The comparison between the two approaches is performed with non -parametric techniques that require only a very reasonable assumption: the relationship between Amax and Imax is monotonically increasing, with no constraint about its functional shape, and gives an equivalent acceleration from intensity Aint. We define a normalised variable of hazard variation HV=Amax/(Amax-Aint), that shows no correlation with Amax or with the number of site felt intensities. The most striking result is the mapping of HV on the Italian territory considering the seismogenic zoning used by PRSTN04. All the sites outside seismogenic zones show high negative values. Site inside seismogenic zones have all the same sign for the same zone, with positive maxima in the zones with highest seismicity rates. Three possible explanation are examined: 1) the catalogue used for PRSTN04 is not Poissonian, and this adversely affect the Cornell-McGuire method; 2) The majority of seismogenic zones does not satisfy the Bender criterion to avoid numerical instability in seismic hazard assessment by standard computational codes (e.g., SeisRisk); 3) Seismogenic zones have a too high variability of seismic activity rates, deriving from the absence of objective criteria in their design.

## SEISMIC HAZARD DISAGGREGATION STUDIES. APPLICATION TO MAINLAND PORTUGAL – ID 623

*M. L. Sousa, National Laboratory for Civil Engineering, Portugal*
*A. Campos Costa, National Laboratory for Civil Engineering, Portugal*

Statement of the Problem: Earthquake scenarios are used in different domains of activities like: (i) civil protection disaster preparedness, (ii) computing overall seismic losses for a portfolio of assets, or (iii) evaluating time histories and duration of ground motion to be used in seismic design and retrofitting. However, the choice of an earthquake event is often based on deterministic arbitrary assumptions, for instances, the worst historical event reported in the region under analysis.

Purpose: The purpose of this work is to overcome the disadvantages of a deterministic approach, choosing a scenario ground motion, for each of the 278 Mainland Portuguese counties, based on a probabilistic seismic hazard disaggregation analysis.

Methods: Probabilistic seismic hazard for Mainland Portugal is reevaluated in order to perform hazard deaggregation analysis. Probabilistic seismic hazard was disaggregated considering different spaces of random variables. They were analyzed: (i) univariate conditional hazard distributions in M (magnitude), R (source-to-site distance) and $\epsilon$ (deviation of ground motion to median value predicted by attenuation law), (ii) bivariate conditional hazard distributions in M-R and in X-Y (seismic source latitude and longitude) and (iii) multivariate conditional hazard distributions in M-R-$\epsilon$ and M-(X-Y)- $\epsilon$.

Application and results: Modal values of the above mentioned distributions were computed for each county of Mainland Portugal. Those values correspond to seismic scenarios that dominate the hazard for each site. When modal seismic hazard scenarios are substituted in the attenuation law they reproduce the target conditional hazard level with a maximum relative error of 2,8%.

Conclusions: 1. Hazard modal scenarios reproduce hazard maps with great accuracy. 2. Hazard scenarios obtained by geographic hazard disaggregation, in X-Y, also reproduce the location of scenarios obtained by disaggregation in M-(X-Y)-$\epsilon$, saving computational efforts. 3. Seismic hazard of most Portuguese Mainland counties is dominated by the seismicity located offshore, southwest of S. Vicente cape.

## ON THE IMPACT OF THE BINNING STRATEGY ON MACROSEISMIC MAGNITUDE-DEPTH-IO ESTIMATES – ID 625

*D. Baumont, IRSN, France*
*O. Scotti, IRSN, France*

Macroseismic data are used to compute the density probability function for magnitude-depth-and Io solutions related to modelling uncertainties. This calculation relies on the derivation of empirical attenuation relationships calibrated on different sets of events (75 Ml, 55 Ms, 13 Mw) assuming that regional tendencies are negligible and that attenuation can be modelled through a log(hypocentral distance) formulation. Using the twenty best recorded events covering the French territory, we show first, that apparent changes in attenuation slopes are due to lack of completeness in the data set, at large distances, and to an erroneous depth estimate, at short distances. Secondly, the computed intensity attenuations strongly depend on the binning strategy applied (intensity or distance binning). Apparent slopes of intensity binned data (-3.35 $\pm$ 0.10) are systematically steeper than the ones derived on distance binned data (-2.74 $\pm$ 0.10). Through an analysis of synthetic intensity distributions, we show that the local variability of the intensity assignments and their spatial distributions at large distances bias the slope estimates based on intensity binning. By applying a spatial filter to the observed intensity assignments, it was possible to reconcile the slopes derived using the two strategies. We also show that the computation of isoseismals may be equivalent to apply a spatial filter, depending on the scheme used. These findings suggest that the difference of slope results derived for other countries (Italy, USA, UK, NW Europe) may be controlled to a large extent by the choice of their binning strategy rather than differences in the physical characteristics of each country. Finally, for each binning strategy, various data selection and minimisation schemes were used to explore the uncertainty domain of the attenuation coefficients and compute the magnitude-depth-Io probability density function. Preliminary results indicate that the different binning strategies lead to similar predicted macroseismic magnitudes but differ on the depth and Io estimates.

## PROBABILISTIC SEISMIC HAZARD ANALYSIS USING MAPPING TECHNIQUES AND EPICENTER DENSITY FUNCTIONS – ID 644

*J. Habenberger, Bauhaus-Uni, Germany*

In regions with low or moderate seismicity it is difficult to achieve both an exact description of magnitude recurrence relation and detailed determination of spatial seismicity. Furthermore the derivation of regionalisation models is influenced by subjectiveness. In the paper a new zoneless approach is proposed for probabilistic seismic hazard analysis. Spatial distributions of the parameters of the Gutenberg-Richter-relation are given by applying Voronoi diagrams and mapping techniques to the historical earthquake catalogue. Artificial earthquake catalogues are derived from the zoneless model and applied to probabilistic seismic hazard analysis. The results are compared to those of common regionalisation methods.

## EARTHQUAKE AND MICROTREMOR SITE RESPONSE AT INTERNET ACCELEROGRAPH SITES IN BRITISH COLUMBIA, CANADA – ID 693

*S. Molnar, University of Victoria, Canada*
*A. Rosenberger, Natural Resources Canada, Canada*
*S. Dosso, University of Victoria, Canada*
*J. Cassidy, Natural Resources Canada, Canada*

In 2002 the Geological Survey of Canada began the process of replacing stand-alone instruments in its existing strong motion network across southwestern British Columbia with Internet Accelerograph (IA) instruments that communicate in near real-time over the Internet. The instrument stores data in its ring buffer, irrespective of whether an event is detected or not, and the data can be directly retrieved over the Internet at any time. These "new" features of the strong-motion instrument network have provided over 150 low-level (1.4% g maximum) ground motion recordings across southwestern British Columbia from five earthquakes, ranging in magnitude from ML 3.6 to ML 6.1. We examine the peak ground acceleration and velocity recorded from these five earthquakes compared with numerically determined attenuation relationships for the Cascadia region of southwestern British Columbia and northwestern Washington. We also investigate the site response of our IA stations by comparing the average microtremor horizontal-to-vertical spectral ratio with the horizontal-to-vertical spectral ratios from these five earthquakes.

## DEVELOPING THE UHS FOR NEW SITE OF ISLAMIC AZAD UNIVERSITY (IAU) - SOUTH TEHRAN BRANCH - IN IRAN – ID 910

*M. Firoozi Nezamabadi, Islamic Azad University (IAU)-South Tehran Branch, Iran (Islamic Republic Of)*
*F. Yaghoobi Vayeghan, Transportation Research Institute (TRI), Iran (Islamic Republic Of)*

A site investigation as well as a Seismic Hazard Analysis (SHA) has been carried out for new site of an important university in north-east of Tehran (capital of Iran). The aim has been estimating the level of seismic hazard for the site and developing the Uniform Hazard Spectra (UHS) for horizontal as well as vertical component to design its buildings against seismic ground motion more precisely. At first, it was tried to recognize all the active faults around the site. Secondly, by using the appropriate attenuation laws, the PGA values on the site were estimated. These values obtained for the site vary between 0.096g and 0.377g (horizontal) and 0.092g and 0.212g (vertical) for 10% and 0.156g and 0.707g (horizontal) and 0.152g and 0.422g (vertical) for 2% probability of exceedence in 50 years ground motions depending on the applied attenuation laws such as Ambraseys, Ambraseys and Bommer and Zare and Ashtiany. The PGA for vertical and horizontal component using Zare and Ashtiany attenuation relationship obtained 0.212g for 10% and 0.422g for 2% and 0.289g for 10% and 0.575g for 2% exceedence in 50 years ground motion respectively. The ratio of vertical to horizontal component (V/H) is 0.74. This study has shown that V/H increases due to near fault effect. Finally, the UHS, which are more reliable for design purposes, were constructed for the 2% and 10% probability of exceedence in 50 years ground motions.

## EARTHQUAKE RESPONSE VARIATION RANGE BASED ON THEORETICAL GROUND MOTION MODEL – ID 943

*H. Dohi, NTT Facilities Inc., Japan*
*S. Matsuda, Kansai University, Japan*
*M. Kawano, (Belonged to) Kyoto University, Japan*
*K. Asano, Kansai University, Japan*

Large earthquakes have frequently occurred near urban area and brought about enormous damage to structures and facilities. The characteristics of earthquake ground motion are described strongly by not only the site amplification but also the source dynamics. Therefore it is an important problem to predict the variation range of the maximum responses of structural systems due to the characteristics of ground motion. In this study, to describe theoretically the variation range of maximum structural responses during earthquake, the prediction model of earthquake ground motion has been presented on the basis of the wave propagation theory and source kinematics. In this modeling of ground motion, the rupture process on fault plane for a unit event is idealized as an impulse response of elastic membrane. This dynamic response is applied for source modeling as a slip function with the w2 spectral characteristics. Then the source rupture growth process of a large event is modeled as a sum of such slip functions with the rupture events occurring in compliance with a degree of the irregular heterogeneity on the entire fault plane. The refined soil sediment structure model for source-site path is presented as a multi-layered half-space that consists of a surface soil layer overlying a semi-infinite random medium. The possible envelope functions for the maxima and spectral characteristics of earthquake responses of structure system have been evaluated at the several sites using the above ground motion model. As these envelope functions reflect the variation of the soil ground, the source-site distance, the source-site geometry, the ratio of epicentral distance to focal depth, and the directivity effects in the source radiation, they will be useful for the reasonable seismic design of structural system.

## SEISMIC HAZARD AND SEISMIC DESIGN REQUIREMENTS FOR THE ARABIAN GULF REGION – ID 1167

*N. Peiris, Arup, UK*
*M. Free, Arup, UK*
*Z. Lubkowski, Arup, UK*
*A. Hussein, Arup, United States*

This paper presents the results of a regional seismic hazard assessment undertaken for the Arabian Gulf Region. The area studied extends from 10° N to 35° N and 35° E to 65° E. This area includes a number of major regional tectonic features including the Zagros and Makran regions to the north and east, the Dead Sea and Red Sea to the west and the Gulf of Aden and Owen Fracture Zone to the south and southeast, with the stable continental Arabian Plate in the centre of the area. An earthquake catalogue has been compiled and critically reviewed for this area and seismic source zones and their associated magnitude recurrence parameters defined. Attenuation relationships have been selected based on the tectonic character of the source zones. The uncertainty in each element of the assessment has included in the assessment using logic tree methodology.

The seismic hazard results are presented in the form of seismic zonation maps for the Persian Gulf region and uniform hazard response spectra for selected cities in, Qatar, the United Arab Emirates and Oman. The paper also describes how these results might be used for seismic design purposes.

## PROPOSAL OF AN ATTENUATION RELATIONSHIP OF HOUSNER SPECTRUM INTENSITY IN EUROPE – ID 1193

*J. E. Martinez-Rueda, University of Brighton, UK*

The evolution of attenuation relationships is an interesting aspect of Engineering Seismology that has taken a long and fruitful road. Recently (2005), an elaborate attenuation model for Europe (referred here as the ADSS model) has been proposed by Ambraseys, Douglas, Sarma and Smith. The model estimates the attenuation of spectral acceleration as a function of moment magnitude, source-to-site distance, faulting mechanism and local site conditions. On the other hand, past studies have shown that a good correlation exists between spectrum intensity (SI) and ductility demand. This indicates that SI can be used as an objective measure of instrumental intensity for earthquake ground motion as efficient earthquake-resistant structures are expected to behave inelastically under the design earthquake. Based on a parametric study using the ADSS model this paper proposes a semiempirical model to estimate Housner Spectrum Intensity (SIH) in Europe. Accordingly, the proposed model estimates the attenuation of SIH as a function of the same parameters of the ADSS model. Comparisons between observed and estimated SIH values are critically analysed and the potential application of the proposed model for accelerogram scaling and vulnerability analysis is highlighted

### MAPPING OF CRUSTAL STRAIN RATE TENSOR FOR ICELAND WITH APPLICATIONS TO SEISMIC HAZARD ASSESSMENT – ID 1211

*R. Sigbjornsson, University of Iceland, Iceland*
*T. Sigurdsson, National Land Survey of Iceland, Iceland*
*J. T. Snaebjornsson, University of Iceland, Iceland*
*G. Valsson, National Land Survey of Iceland, Iceland*

The objective of this paper is to present the findings of a crustal strain rate analysis for Iceland and, furthermore, to demonstrate its potential applications in seismic hazard assessment. The crustal strain rates are derived using surface measurements applying the global positioning system (GPS). The GPS measurements applied are discussed and the derived average velocity field for an eleven year period, from 1993 to 2004, is presented. The definition of strain rate tensor and spin (vorticity) tensor is outlined and the results of the numerical analysis presented. This includes a discussion on compatibility and its implications for the properties of the derived strain rate field. The tensor rate field is displayed on maps showing normal and shear strain rate field, along with principal strain rate field and dilatation rate field as well as the vorticity field. A special attention is given to measurement uncertainties and the results of uncertainty analysis used to validate the maps and assess their reliability. The derived tensor fields are discussed and interpreted in relation to the present day view on the tectonism of Iceland. Furthermore, they are compared with earthquake activity as well as published earthquake hazard maps for Iceland. Finally, the potential application of the mapped tensor rate field in seismic hazard assessment is outlined and demonstrated. This indicates that the published hazard maps for Iceland can be enhanced, especially in areas with low seismicity where instrumental earthquake data are sparse and information on historic earthquakes is missing.

### SHAKE MAPS OF NONLINEAR SPECTRAL ORDINATES FOR ROMANIAN EARTHQUAKES – ID 1257

*I. G. Craifaleanu, National Institute for Building Research, INCERC, Romania*
*D. Lungu, National Institute for Building Research, INCERC, Romania*
*I. S. Borcia, National Institute for Building Research, INCERC, Romania*

The abstract presents the results of an extensive study, performed on strong earthquakes (moment magnitude larger than 6.0) recorded in Romania in the last 30 years. The study involved mapping of peak ground motion ordinates, as well as of linear and nonlinear spectral ordinates, for seismic events recorded in 1986, 1990 and 2004. In the first part of the study, shake maps were generated for peak ground acceleration, velocity and displacement, effective peak ground acceleration and velocity and for the corner period of response spectra, Tc. The second part focused on the development and analysis of shake maps for linear acceleration and displacement spectra while, in the third part of the study, shake maps were generated for nonlinear, constant ductility, acceleration and displacement spectra.

### DAMAGE DISTRIBUTION AND SEISMOLOGICAL MODEL OF THE NOVEMBER 2004, SALO' (NORTHERN ITALY) EARTHQUAKE – ID 1371

*V. Pessina, INGV, Italy*
*G. Franceschina, INGV, Italy*
*P. Vannoli, INGV, Italy*
*L. Luzi, INGV, Italy*
*F. Pacor, INGV, Italy*

The West side of lake of Garda, in Northern Italy, was struck by a Ml=5.2 earthquake on November 24, 2004. The felt area is rather large (from Venice to Milan) and the damaged area consists of 66 municipalities, with a number of homeless of about 2200 and estimated direct damages of 215 millions of euros. Most of the damaged structures are old masonry buildings and churches, while there were almost no damage to reinforced concrete structures. The observed distribution of macroseismic intensity shows a strong azimuthal dependence, with high intensity level in a 10x10 km2 area located SW to the epicentre and rather large dispersion of values (ranging from V to VII-VIII) in the first 10 km epicentral distance. Taking into account the high vulnerability of the damaged structures and the features of the geological formations, we tried to explain the observed damage distribution in terms of finite fault properties of the source, despite the moderate magnitude of the event. To this aim, we hypothesised a fault geometry from seismotectonic considerations and we simulated the event by a high frequency simulation technique (Deterministic Stochastic Method, DSM). The synthetic ground motion parameters are converted into intensity values by empirical relationships and local geological conditions are considered to explain some discrepancies between simulated and observed intensities. It was possible to adequately reproduce both the observed distribution of macroseismic intensity and the ground motion recorded by an accelerometric station located at about 10 km epicentral distance.

### SEISMOTECTONIC MODELING FOR SEISMIC HAZARD ANALYSIS OF VARDAR ZONE IN THE REPUBLIC OF MACEDONIA – ID 1389

*B. Dimiskovska, IZIIS-Skopje, Macedonia*
*V. Mihailov, IZIIS-Skopje, Macedonia*

The investigations of seismicity, tectonics and geology of the territory of the Republic of Macedonia that have been performed so far have pointed out the direct relationship between the earthquake occurrence and tectonic processes. To define a seismogene source and earthquake occurrence, it is necessary to know the geological evolution of the terrain particularly in contemporary conditions. In the investigated area, the earthquakes have exclusively been of a tectonic origin wherefore the greatest attention has been paid to the activity of the fault structures in the Vardar zone, the correlation between the epicenters of occurred earthquakes and the geological media through which the seismic waves propagate. The seismotectonic map of the Vardar zone clearly shows that the stretching direction of the fault structures correlates with the epicenters of occurred earthquakes. The seismicity model formulated on the basis of data from the seismological and seismotectonic investigations of the region has been the starting point in defining the seismic hazard. Two approaches have been proposed for definition of a seismic model to be used in defining the seismic hazard. A comparison between these models has also been made.

### GROUND MOTION PATTERN OF THE OCTOBER 27, 2004 INTERMEDIATE DEPTH VRANCEA EARTHQUAKE – ID 1407

*K. P. Bonjer, Geophysical Institute University of Karlsruhe, Germany*
*C. Ionescu, National Institute for Earth Physics, Romania*
*V. Sokolov, Geophysical Institute University of Karlsruhe, Germany*
*M. Radulian, National Institute for Earth Physics, Romania*
*B. Grecu, National Institute for Earth Physics, Romania*
*M. Popa, National Institute for Earth Physics, Romania*
*E. Popescu, National Institute for Earth Physics, Romania*

The October 27, 2004 earthquake occurred in the north-eastern end of the Vrancea seismic region. This region is centered in the SE-Carpathians and is confined to an area of about 20 x 60 km2. Weak and strong earthquakes occur at depths between 60 and 180 km on two parallel, almost vertical planes, which are separated by less than 10 km. Joint Hypocenter Determinations locate the earthquake at a depth of 100 km in the more northern trending plane of the background activity. The fault plane solution (225°/80°/95°) shows a nearly pure thrust mechanism, which is typical for the strong Vrancea intermediate depth earthquakes. The October 27 earthquake was a high stress drop event (100-200Mpa) with a moment magnitude of Mw=6. It was the strongest event, which occurred after the May 1990 earthquake sequence with the two main shocks of Mw=6.9 and 6.4. A maximum acceleration of 265 cm/s2 was recorded by the K2 strong motion network,

operated jointly by the Collaborative Research Center 461 'Strong Earthquakes' of Karlsruhe University and the National Institute for Earth Physics, Bucharest. Although the greatest recorded acceleration was close to the peak accelerations of the strong and damaging Vrancea events of 1977, 1986 and 1990, the maximum intensity, calculated on the basis of the Fourier Amplitude Spectra, was only 6.5. This explains why no significant damage was registered. The great number of on-scale observations gives the chance to control macroseismic observations with instrumentally recorded ground motions. In this contribution, we use the 'USGS Community Internet Intensity Map' for the comparison.

## DECONVOLUTION OF SEISMIC DATA USING PARTIAL TOTAL LEAST SQUARES – ID 1433

*A. Chanerley, University of East London, UK*
*N. Alexander, University of Bristol, UK*

The Partial Total Least Squares (PTLS) [1 2] is a variation on the Total least Squares (TLS) [8] which assumes that all the measurents on both sides of Ax = b are noisy. The PTLS assumes that some of the data is known exactly, whereas other parts of the data are produces from noisy measurements.

Essentially the problem is still finding the solution of Ax = b by forming the combined matrix C = [A b] in order to reduce the rank of C. However, the rank is reduced by modifying only some of the rows/columns of the matrix C.

The seismic data used for the analysis is chosen as far as possible such that instrument parameters were retained in the header files of the seismic record [6,7]. These include data from the SMART-1 array in Taiwan which provide some details of the anti-alias filter used. For other digital records which didn't give details of any anti-alias filter, these were inferred from the sampling rate, on the assumption that an anti-alias with a cut-off at half the sampling rate, would have been used.

The PTLS was applied to the seismic data after wavlet denoiseing and correcting for baseline, but without any frequency selective filtering.

Keywords: Correction, filter, seismic, wavelet, de-noising, recursive, least squares, band-pass, filtering, filter, inverse filter, convolve, de-convolve

## MITIGATION OF THE SEISMIC HAZARD AND RISK IN MONTREAL – ID 1453

*P. Rosset, c/o University McGill, Canada*
*A. De La Puente, University McGill, Canada*
*L. Chouinard, McGill, Canada*

Montreal is ranked second in Canada in terms of seismic risk after Vancouver. An exhaustive analysis of seismic hazard was coupled to structural vulnerability assessments to provide the civil protection agency and stakeholders with maps and scenarios for seismic mitigation and prepardness. Microzonation maps including liquefaction potential are used to identify buildings, bridges and lifelines vulnerability for various levels of ground motions. The objective of this paper is to outline results that have been obtained to date in the seismic hazard project and how the information has been used for emergency preparedness. On-going projects to supplement current information are also outlined.

## A REVIEW OF SEISMIC VULNERABILITY ASSESSMENT IN MEXICO CITY, FROM LARGE SUBDUCTION EARTHQUAKES – ID 1466

*A. Gomez Bernal, Universidad Autonoma Metropolitana, Mexico*
*H. Juarez Garcia, University of British Columbia, Canada*

In this paper one of the objectives is to obtain detailed maps of the expected distribution of damage buildings, for a given earthquake scenario. Results from the damage estimation of one of the most vulnerable zones in Mexico City: Delegacion Cuahutemoc, are shown.

Damage statistic surveys after the July 7, 1957, and the September 19, 1985 earthquakes in Mexico City, were used in order to obtain proper vulnerability functions for masonry and reinforced concrete buildings.

The values for the damage probability matrices (DPM) proposed in the European Macro Seismic Scale (EMS98) were used without further modification for masonry structures; however for concrete structures with more than 6 storeys DPM and vulnerability functions from EMS98 scale are rather different, this unique difference is due to the extreme response amplification that buildings, with 0.5 to 2.5 sec of period, experienced in the 1957 and 1985 earthquakes.

Microzonation of the studied zone has been achieved using Peak Ground Accelerations (PGA), Peak Spectral Accelerations (PSA), and Maximum Ductility Demands (MDD) distributions, from several past recorded earthquakes with M > 7.0 and with different seismic origin (January 1997, April 1989, June 1999, and September 1999), therefore Iso-intensity maps are drawn showing the intensity variation within the studied zone for a given damage scenario.

## SPATIAL VARIATION OF GROUND MOTION IN ISTANBUL – ID 1633

*E. Harmandar, Kandilli Observatory and Earthquake Research Inst., Turkey*
*E. Durukal, Kandilli Observatory and Earthquake Research Inst., Turkey*
*M. Erdik, Kandilli Observatory and Earthquake Research Inst., Turkey*
*O. Ozel, Kandilli Observatory and Earthquake Research Inst., Turkey*

The spatial variation of earthquake ground motions can occur as a consequence of soource properties, wave propagation through different earth strata, soil media and topographic features and serves to quantify the amplitude and phase differences of ground motion over distance or area. The spatial variation of earthquake ground motion has an important effect on the response of linear lifelines such as bridges, pipelines, communication systems, and should preferably be accounted for in their design. In this study, spatial variation of strong-ground motion in Istanbul from two earthquakes recorded by the Istanbul Earthquake Rapid Response and Early Warning System (IERRS) is analyzed. The first event (ML 4.3) took place on 16.05.2004 off the Yalova coast in the Eastern Marmara Sea close to the entrance of the Izmit Bay. The second one (ML 4.0) occurred on 29.09.2004 to the south of the Prince islands close to Istanbul. The spatial variance of motion within the network is investigated by the analysis of the intra-event variation of peak horizontal accelerations (PHA) and pseudo spectral velocities (PSV), as well as by coherency analysis. The intraevent spatial variability of PHA's is examined by the PHA ratio of two stations as a function of separation distance over a frequency range of 0.2 to 25 Hz. The analysis is repeated using ratios of PSV's of station-pairs calculated as the average of PSV's between 0.2 and 1.0 s periods for 5-percent critical damping, and plotted against station-separation distance. The results are preliminary in the sense that so far two events were recorded by the larger number of stations in the IERRS This work forms the skeleton of an automated system to uniformly calculate the variance of recorded motions. It is expected that the results obtained will stabilize and become more reliable as the number of recorded events increase.

## AMBIENT VIBRATION MEASUREMENTS IN LJUBLJANA, SLOVENIA – ID 1654

*P. Zupancic, Environmental Agency of the Republic of Slovenia, Slovenia*
*B. Sket Motnikar, Environmental Agency of the Republic of Slovenia, Slovenia*
*A. Gosar, Environmental Agency of the Republic of Slovenia, Slovenia*

In the frame of the NATO – Science for Peace project "Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the FYR of Macedonia, Croatia and Slovenia", we performed ambient vibration survey of Ljubljana, the capital of

Slovenia. The goal of this project is to equip partner countries with the state-of-the-art seismic noise (ambient vibration) measuring/processing instrumentation, which will enable to characterise the dynamic behaviour of large sets of soil deposits and buildings. The aim is also to perform very detailed microzonation of urban areas by overlaying soil frequency map with building frequency map and to identify the locations of potential soil-structure resonance that could increase the damage in the area. Ljubljana basin is a region of increased seismic hazard and at the same time the most densely populated area in Slovenia. The strongest earthquake in the history of the city occurred in 1895 (M=6.1, I0=VIII-IX MSK). We performed free-field measurements in 200 x 200 m grid and measurements in approximately 100 buildings (residential, elementary schools and health centres). In buildings, measurements were performed at all floors. For the purpose of organising and presenting the collected information we prepared the field-questionnaire and set up a database which includes all important information about the surveyed building (e.g. address, height, age, construction material, measured fundamental frequency of the building in both directions and of near free-field). To obtain fundamental frequency of buildings, the data were analyzed using power spectra, horizontal to vertical spectral ratio (HVSR) and standard spectral ratio (SSR). To obtain fundamental frequency of soil, the data were processed using HVSR and the results were compared to the estimated thickness of the sedimentary cover of the basin. Case studies of some characteristical parts of Ljubljana are presented.

## NEW GENERATION OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF GERMANY – ID 1696

*G. Grünthal, GeoForschungsZentrum Potsdam, Germany*
*C. Bosse, GeoForschungsZentrum Potsdam, Germany*
*D. Stromeyer, GeoForschungsZentrum Potsdam, Germany*
*R. Wahlström, GeoForschungsZentrum Potsdam, Germany*

Probabilistic Seismic Hazard Assessment (PSHA) is, in contrary to deterministic methods, widely considered the most credible method to calculate the earthquake hazard. It is a key element in seismic risk calculation and thus an important tool in the mitigation of the effects from future earthquakes. Its results require updates when novel data and improved scientific insights become available. Germany, although a country of low to moderate seismicity, is exposed to considerable seismic risk due to the combined effect of the high degree of industrialization, infrastructure and high population. The population density is especially high in several of the most earthquake prone areas. Innovations implemented in the present study are a much improved, Mw based earthquake catalogue for Germany and the surrounding area, new ground motion relations, with regard taken to the faulting style, new large- and small-scale seismic source zone models, and new methods to calculate the maximum expected magnitude and the focal depth distribution. Declustering and completeness algorithms for the catalogue entries are specified. Modern PSHA as applied here includes the uncertainties in all input elements. Both the aleatory uncertainty, describing the intrinsic variability of nature which cannot be reduced with additional or more accurate data, and the epistemic uncertainty, the result of inaccurate or incomplete information which can be reduced when additional observations, better models or increased scientific knowledge become available, are considered. The use of the logic tree technique facilitates the incorporation of a range of realistic values, functions or models for each input parameter. Consequently, the resulting hazard is expressed in terms of fractiles for the probability of exceeding various ground motion values. Maps of expected spectral accelerations and intensities are produced. Although the general patterns resemble those of previous maps, there are obvious changes in some areas.

## PROBABILISTIC SEISMIC HAZARD ANALYSIS OF NORTHERN ANDES: A COMPARISON BETWEEN DIFFERENT APPROACHES – ID 1729

*E. Fiorini, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Tibaldi, Dipartimento Scienze Geologiche Uni Milano-Bicocca, Italy*
*G. Zonno, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*M. Garcia-Fernandez, Inst. de Ciències de la Terra "Jaume Almera", Spain*

Most of the seismic hazard studies of the Northern Andean region, i.e. Colombia and Ecuador, are part of wider regional studies covering the whole of South America (e.g. CERESIS 1996, PILOTO 1999). Existing national hazard maps for Ecuador and Colombia normally do not include information about the input data and parameters used to generate them. We have produced seismic hazard maps of the Andean region north of latitude 6°S using areal source zones and time-independent PSHA approach. Based on the earthquake catalogue and the areal source model of the PILOTO project we have defined an intermediate and a large scale source zonation by combining the information from seismicity, geology and tectonics, trying to better modelling both the subduction and the crustal sources. Hazard computations have been carried out using the CRISIS code (Melendez and Ordaz, 2001), which allows for inclined seismic sources, and is therefore useful in modelling the geometry of subduction zones. The quality of the catalogue locations and the limited knowledge on the geometry of the subducting slab does not allow for an accurate association of intermediate and deep events with a well-defined structure at depth. The crustal sources are also partially affected by these uncertainties. Alternative approaches to the source model have been tested, including a 'zone-free' model and a combination of areal sources and smoothed seismicity to model respectively the shallow (crustal and interface) and the intra-slab events. The different results have been examined and the limits and points of strength of the different approaches are discussed.

## DEFINING THE EARTHQUAKE EFFECTS AT A GIVEN SITE – ID 1737

*L. Timiovska, IZIIS, Macedonia*

The determination of the spatial distribution of the released energy from the focus to a given point is known as an attenaution problem. The main task being to determine the size of a given parameter defining the earthquake effects at a given site(intensity, maximal acceleration, velocity or displaceemnt) as a function of the parameters describing the size of earthquake(magnitude, epicentral intensity, seismic moment), the distance and the soil conditions. For each of earthquke included in this analysis the distance from the epicenter to each point of a certain intensity have been measured and represent the basic data.

## OBSERVATIONS FROM REGRESSIONS ON GROUND MOTION DATA FROM BRITAIN AND NORTH-WESTERN EUROPE – ID 1741

*S. Sargeant, British Geological Survey, UK*
*R. Musson, British Geological Survey, UK*

Regressions were carried out on two peak ground acceleration datasets. The first dataset contains observations from UK earthquakes ranging from –0.7 to 5.1 ML recorded over distances of 1-441 km. The second contains data from earthquakes of similar magnitude (1.9-5.9 ML) compiled by Free et al. (1998) for north-western Europe. Individual regressions on these datasets suggest that attenuation in these two regions is similar. In light of this, the datasets were combined and further regressions carried out. We compared these results with the relations of Ambraseys et al. (1996), which are based on data from larger earthquakes and which have been applied in UK hazard assessments. At magnitudes less than around 4.9 ML, our relation estimates realistic ground motions whereas those calculated using Ambraseys et al. (1996) are significantly higher. At 5.5 ML and above, our relation predicts unrealistically high accelerations (up to three times higher than those estimated using Ambraseys et al., 1996). However, between 4.9-5.0 ML, the two relations coincide for distances of 50 km or less. This result implies that there is some effect of magnitude that neither relation accounts for. For the realistic prediction of ground motion for the entire range of magnitudes, a hybrid approach may

be necessary.

### EARTHQUAKE SCENARIOS FOR THE CITY OF SOFIA – ID 1763

*D. Solakov, Geophysical Institute, Bulgaria*
*S. Simeonova, Geophysical Institute, Bulgaria*

The city of Sofia that is the main administrative center in Bulgaria, with the densest population is exposed to a high seismic risk. The earthquakes that mainly influence the hazard in Sofia originate either near the town or are caused by regional seismic sources. The seismogenic features of the area of about 200 km around the city of Sofia were analyzed considering seismicity, neotectonics and geological development. The ground shaking scenarios for the Sofia municipal area were generated using both deterministic and probabilistic approach. A reliable geotechnical zonation of the city of Sofia was incorporated in the earthquake scenarios generation. The probabilistic seismic hazard assessment in terms of peak ground acceleration and response spectral accelerations for different values of the vibration period is performed. The PSHA is based on a simplified seismogenic model, which is derived from seismic zoning of Bulgaria. We show, using a Monte Carlo approach, that uncertainties in seismic input have a relatively little effect on the PSHA output, especially when compared with uncertainties associated with the attenuation relationship. Both deterministic and constant hazard ground motion scenario are produced, consisting of maps showing response spectral ordinates at selected vibration periods over the urban area. These scenarios may be efficiently used as a basic input for developing relatively detailed earthquake damage scenarios for the city of Sofia. The material presented is the outcome of part of Bulgarian work carried out in the Risk EU Project (2001-2004) funded by The European Economic Commission in the framework of the Fifth Research and Technological Development Program "Energy, Environment and Sustainable Development".

### HAZARD MAPS FOR PORTUGAL: SENSITIVITY TO SEISMIC ZONATION AND ATTENUATION MODELS – ID 1802

*S. Vilanova, Instituto Superior Tecnico, Portugal*
*J. Fonseca, Instituto Superior Tecnico, Portugal*

Mainland Portugal is located in the vicinity of the Azores-Gibraltar plate boundary, under the influence of the continental convergence between Iberia and the African Plate, and its hazard has contributions from both interplate and intraplate seismicity. The diffuse character of the Azores-Gibraltar boundary East of the Gorringe Bank (long 12W) leads to significant intraplate deformation in areas of localized weaker lithosphere. Previous work on seismic hazard assessment for Portugal focused on the seismic catalogue input, namely the completness analysis, the conversion of magnitudes and the estimation of recurrence laws. Much effort was dedicated to this specific node of the logic tree analysis because it represents the only regional input, since no ground motion models are available for the region. To characterize the attenuation we used ground motion models for stable and active continental regions, weigted according to the fit to PGA-converted macroseismic data. This procedure was adopted given the scarcity of ground motion data for engineering-relevant magnitudes and distances and the fact that different types of crust may be involved in the seismic attenuation. In this work we present new hazard maps for SW Iberia emphasizing the discussion on how the seismic zonation affects both the hazard pattern and the hazard absolute values. The results indicate that the hazard for Algarve is lowered when this zone is included on the southern active tectonic region. Irrespective of the chosen zonation, we obtain the maximum regional hazard at the Tagus Valley region. This contrasts with other studies that used ad-hoc attenuation laws derived from intensities and gave the regional maximum in the Algarve. This may be the result of a bias introduced by intensities estimated for the 1755 earthquake.

### PSHA FOR NORTH-EASTERN ITALY – ID 1832

*D. Slejko, OGS, Italy*
*A. Rebez, OGS, Italy*
*M. Santulin, OGS, Italy*

The logic tree approach has been used to compute robust seismic hazard estimates for north-eastern Italy (Friuli - Venezia Giulia and eastern Veneto regions). These hazard estimates were planned to be used for the expected damage assessment at a regional scale. In order to quantify the epistemic uncertainties, the logic tree approach has been followed. Our logic tree consists of 54 branches for rock and soft soil conditions: three seismogenic zonations, representing various levels of our seismotectonic knowledge, three methods for the seismicity rate computation, three statistical approaches for the maximum magnitude estimation, and two PGA attenuation relations of different spatial relevance (Italian, European) were used. For stiff soil conditions, an additional attenuation relation of regional applicability was considered with an enlargement of the logic tree to 81 branches. The regional hazard assessment was done according to a standard probabilistic approach for several return periods: 189 runs were processed in total. The hazard estimates coming from all branches, contribute to the final aggregate seismic hazard map. Two areas (central Friuli and the area around Vittorio Veneto) show the highest hazard in these maps. All results were stored and elaborated by a GIS system, which allowed us to produce the final soil hazard map. The computed PGA with a return period of 475 years in Vittorio Veneto (stiff soil conditions) is 0.38 g, considering the aleatory variability; it becomes 0.51 g when the epistemic uncertainties are added. For damage assessment purposes, an additional hazard map in terms of macroseismic intensity has been obtained transforming the PGA estimates into intensity by a relation calibrated on the data of the 1976 Friuli earthquake. The intensity hazard map shows similar features as those of the hazard map in terms of PGA with the maximum values along the northern Tagliamento river valley.

### PROBABILISTIC SEISMIC HAZARD IN A LOW SEISMICITY COUNTRY (FRANCE): CAN THE OBSERVATIONS FROM THE STRONG-GROUND MOTION ARRAY BE USED TO VALIDATE THE ESTIMATES ? – ID 1886

*C. Beauval, IRD-Geosciences Azur, France*
*P. Y. Bard, LGIT, France*
*P. Gueguen, LGIT, France*

Probabilistic hazard estimates have recently been the subject of intense debates in France. Indeed, rather different estimations resulted from studies led by various institutions/universities (Autran el al. 1998, MEDD 2002, Marin et al. 2004, Beauval 2003). The question of using observations to validate/invalidate estimations is thus becoming of crucial interest. Assuming a Poissonian occurrence for earthquakes, probabilistic hazard methodologies aim at computing rates of exceedance of given ground motion levels at the sites of interest. Thus, a natural way of testing the probabilistic method would be to compare estimated rates and observed ones. However, we show that in low-seismicity regions such as France, this comparison cannot be done for the acceleration levels of interest in the building codes (corresponding to return periods of hundreds to thousands years). Observation periods are too short with respect to the frequency of these ground-motions. Simulation of Poissonian occurrences demonstrate that comparing observed rates with calculated ones leads to erroneous conclusions if too low frequencies of occurrence are considered. The minimum observation time windows for computing statistically significant mean rates are estimated. Observations at the stations of the French strong motion RAP array indicate that acceleration levels for which the comparison is meaningful are far below levels of interest for engineering purposes. One may however expect a meaningful comparison, under some specific conditions: when hazard studies are performed with attenuation relationships that are valid over a wide magnitude and distance range, and small minimum magnitude values, and when sensitive accelerometric stations are used providing recordings much below the old "0.01 g" threshold (down to 10-4 or at least 10-3 g).

### HAZARD DISAGGREGATION: THE IMPORTANCE OF MULTIPLE OCCURRENCES – ID 1972

*M. Pagani, IDPA-CNR, Italy*
*A. Marcellini, IDPA-CNR, Italy*

Probabilistic seismic hazard disaggregation can be nowadays a fundamental tool for back-analysis of calculated hazard values and more generally for the selection of hazard-representative time histories. The common procedure to select representative time-histories usually relies on the magnitude (m), distance (r) and epsilon (e) triple giving the largest contribution to the disaggregated hazard. In this work, in addiction to the classically disaggregated variables, we discuss on contributions to hazard due to single and multiple occurrences using a new probabilistic seismic hazard disaggregation technique. We discuss the results of this disaggregation technique using three source models owing to intermediate and high seismicity areas. Our findings, considering the ground motion parameter (PGA) with 10% and 2% probability of being exceeded in 50 years, show a larger importance of inter-event ground motion variability in the gridded seismicity source model in respect of the fault source model where intra-event variability seems more critical for the characterization of the hazard.

### IS THE VS30 A RELIABLE MEASURE OF SOIL CLASSIFICATION ? – ID 1993

*C. Eva, Dip.Te.Ris.-University of Genoa, Italy*
*R. De Ferrari, Dip.Te.Ris.-University of Genoa, Italy*
*S. Barani, Dip.Te.Ris.-University of Genoa, Italy*
*G. Ferretti, Dip.Te.Ris.-University of Genoa, Italy*

The velocity of S waves averaged on the first 30 meters, Vs30, of a soil column represents an usual factor for classifying soils in different ground types (e.g, Italian building code, the Eurocode 8) each of which is characterized by a specific elastic response spectrum. In this work a database of more than 50 boreholes and related downholes, which have been collected for some municipalities in Molise Region (Southern Italy), are used to compare the Vs30 values and the amplification factors (Fa), estimated for each measurement point, in order to assess the reliability and the accuracy of soil classifications based on Vs30 values. The amplification factors are estimated on the basis of 1D numerical simulations, are carried out to evaluate the amplification function, AF(f), at each site. For this purpose, a suite of real accelerograms (seismic input), selected after the disaggregation of seismic hazard, is driven through a model of the soil column. Amplification factors are estimated as the ratio between spectral intensity of output (soil surface pseudo-velocity response spectrum) and input (pseudo-velocity response spectrum at bedrock level). Vs30 values are related to both Fa values, computed for different frequency ranges, and impedance contrasts. The results show that the use of Vs30 may lead to inaccurate soil classifications and, therefore, to overestimates or underestimates of the ground response of a site. Resonance frequencies and amplification levels should be considered for soil classifications and for the evaluation of the seismic response in order to reduce the bias due to the use of Vs30 only.

### OVER-ESTIMATION OF PROBABILISTIC SEISMIC HAZARD DUE TO THE SPATIAL UNIFORM DISTRIBUTION OF SEISMICITY – ID 2020

*C. Beauval, IRD-Geosciences Azur, France*
*S. Hainzl, Potsdam University, Germany*
*F. Scherbaum, Potsdam University, Germany*

In order to compute probabilistic seismic hazard, seismic sources must be characterized. In low-seismicity regions, seismicity is rather diffuse and faults are difficult to identify, thus large aerial source zones are mostly used. The seismicity is supposed to be uniformly distributed inside each aerial source zone. In this study, the impact of this hypothesis on the probabilistic hazard is quantified through the generation of synthetic fractal seismicity distributions. The impact quantifies the deviation of the "true" hazard values from the uniform hazard estimate. Results show that the spatial uniform distribution leads globally to an over-estimation of probabilistic hazard values. Correlations between D-values and impacts are derived, so that in real cases uncertainty bounds on hazard can be deduced from D-value estimates.

## SC-F 1: Approaches to Model Seismic Scenarios
Level 2

### STOCHASTIC MODELING OF PORTUGAL MAINLAND GROUND MOTIONS – ID 1032

*A. Carvalho, LNEC, Portugal*
*A. Campos Costa, LNEC, Portugal*
*C. Sousa Oliveira, IST, Portugal*

Predictions of strong motion in Portugal make the use of well-founded physical models imperative. This work uses a non-stationary stochastic seismological model, based on random vibration theory, for calculating response spectra and synthesizing strong ground motion acceleration records for Portugal Mainland. Because of the lack of reliable data and the uncertainties on the seismotectonic, very few studies for Portugal concerning source and path effects have been undertook. We based some of our model parameters from data from intraplate earthquakes in continental regions, like East North America, whose response spectra have often been considered to be representative of intraplate conditions around the world. Modifications are then made to fit the recorded ground motion in Portugal Mainland. The validation and comparison are entirely in terms of 5% damped pseudo absolute response spectra for acceleration, The dataset used includes horizontal components of ground acceleration records (M4.0 to 5.3 and distances from 30 to 300 km) obtained by the portuguese digital accelerographic network, on hard sites. This calibrated model was used as the basis for characterization of stronger earthquakes considering a finite fault rupture modeled as a sum of a number of point sources distributed spatially and temporally. Response Spectra are computed for records simulated at many azimuths, for a wide range of magnitudes and distances, for rock sites. The stochastic ground-motions relations were obtained using attenuation parameters based on regional data and so provide a sound basis for estimation of ground motions of Portugal Mainland.

### MODELING THE 1980 IRPINIA EARTHQUAKE BY STOCHASTIC SIMULATION. COMPARISON OF THE SEISMIC SCENARIOS USING FINITE-FAULT SIMULATION METHODS – ID 1694

*G. Zonno, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Carvalho, Laboratório Nacional de Engenharia Civil - LNEC, Portugal*

To define more accurately the near field and the directivity effect, different methodologies of finite-fault modelling have been used to describe the behaviour of ground shaking based on deterministic, stochastic and hybrid stochastic-deterministic approaches as in the framework of the ongoing European project "LESSLOSS – Risk Mitigation for Earthquakes and Landslides". In this study, we simulate and compare seismic scenarios obtained from the complex source characteristic of the 1980 Irpinia earthquake, M 6.9, Southern Italy, using two finite-fault numerical approaches including the dynamic corner frequency approach of Motazedian and Atkinson [2005]. The approach RSSIM [Carvalho et al., 2004] is a non-stationary stochastic simulation method that synthesizes the ground motion due to an extended source by means of an appropriate number of sub-sources, radiating as omega-square point sources. Differently from EXSIM [Motazedian and Atkinson, 2005], RSSIM avoids the computation of acceleration time series

representing the contribution of each sub-fault, but synthesizes the ground motion due to the entire fault from the Power Spectral Density Function (PSDF) radiated by each sub-fault, using the random vibration theory and the extreme values statistics. In addition, RSSIM allows multiple rupture using several segments of faults. EXSIM code was changed to included multiple rupture. The shaking scenarios are computed in terms of Response Acceleration Spectra (PSA), time series, peak ground acceleration (PGA) and peak ground velocity (PGV) at bedrock level. Source and path propagation parameters taken from other studies were tested and the computed shaking scenarios are compared to acceleration records from several stations of Italy. Results are here presented in terms of PGA maps for south Italy.

### SIMULATING EARTHQUAKE SCENARIOS IN THE EUROPEAN PROJECT LESSLOSS: THE CASE OF THE METROPOLITAN AREA OF LISBON (MAL) – ID 1700

*G. Zonno, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Akinci, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*G. Cultrera, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*G. Franceschina, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*F. Pacor, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*V. Pessina, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*M. Cocco, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*A. Carvalho, Laboratório Nacional de Engenharia Civil – LNEC, Portugal*
*E. Coelho, Laboratório Nacional de Engenharia Civil – LNEC, Portugal*
*A. Campos Costa, Laboratório Nacional de Engenharia Civil – LNEC, Portugal*

In the framework of the ongoing European project "LESSLOSS – Risk Mitigation for Earthquakes and Landslides" two sub-projects are devoted to earthquake disaster scenario predictions and loss modeling for urban areas and infrastructures. This paper is dealing with the sub-project 10, SP10, Task Programme "Scenario earthquake definitions for three cities". Finite-fault seismological models are proposed to compute the earthquake scenarios for three urban areas – Istanbul (Turkey), Lisbon (Portugal) and Thessaloniki (Greece). For each case study, ground motion scenarios are developed for the most probable two events with different return periods, locations and magnitudes derived from historical and geological data. In this study, we simulate the accelerometric time series and response spectra for high frequency ground motion in the city of Lisbon and surrounding counties (Metropolitan Area of Lisbon), using two possible earthquake models: the inland source area of Lower Tagus Valley, M 5.7 (4.7) and a hypothesis of the offshore source area of the 1755 Lisbon, M 7.6. The non-stationary stochastic method RSSIM (Carvalho et al. 2004) and a new hybrid stochastic-deterministic approach, DSM (Pacor et al., 2005) are used in order to evaluate the ground shaking and to characterize its spatial variability. Then the site effects are evaluated by means of an equivalent stochastic non-linear one-dimensional ground response analysis of stratified soil profile units properly designed. Results are here presented in terms of PGA maps, for offshore and inland scenarios. The mean and worst shaking scenarios for the Metropolitan Area of Lisbon have been delineated at the bedrock. Local effects amplify the synthetic PGA values by approximately a factor of 2. This means that PGA values computed for bedrock in Lisbon city can increase from 0.12g up to 0.25g and up to 0.5g in surroundings, for the inland scenario, and from 0.045g up to 0.090g for a M7.6 offshore scenario.

### PAST AND PRESENT OF MACROSEISMICITY INVESTIGATIONS – ID 1736

*L. Timiovska, IZIIS, Macedonia*

The design of structure in seismically active regions is based on forecasting of ground motion due to earthquakes. Although for the last decade, many investigators have found ways of computing ground motion, many quastions have remained disputable among scientists and engineers. For example, the problem of which parametrs for prediction of ground motion should be mapped is still disputable. Namely, the maps of maximal ground acceleration and velocity are of little use for the geotechnical engineers who compute potential soil failures. These are of more use for the structural engineers who need input seismic parameters. The proposed engineering procedures should yield results with sufficient accuracy of evaluation of the ground motion with a certain return period. The objective of this engineering procedure is to use historic data as well as geological ones if available. The problem of effect of the local soil medium upon the size of the ground motion has been known for many years. In solving this problem, physical-mechanical models are established by use of empirical data. This problem has been solved worldwide partialy deterministically and probalistically, but not in a comparative way. More preciely, the interpretation of the macroseismic data in respect to their application in zoning requires their transformation in the field of seismic effects and evaluation of the intensity of the shock at a certain site or some specific part of the site. Macroseismicity remains the most efficient way of estimating the reliability in evaluation of the seismic hazard obtained through different methods. On the other hand, the anaysis of the seismic hazard through both approaches would enable evaluation of the future earthquake potential of a certain region, which is of special concern in anticipating measures for protection of the buildings and the human potential.

### GIS-BASED GEOTECHNICAL CHARACTERIZATION OF THE VEGA BAJA (SE SPAIN) AND ITS APPLICATION TO SEISMIC MICROZONATION STUDIES – ID 1776

*A. Ribo, Institute of Earth Sciences "Jaume Almera" CSIC, Spain*
*M. J. Jimenez, Institute of Earth Sciences "Jaume Almera" CSIC, Spain*
*M. Garcia-Fernandez, Institute of Earth Sciences "Jaume Almera" CSIC, Spain*
*F. Meroni, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. Molina, Faculty of Sciences, University of Alicante, Spain*

A geological, geotechnical, and geophysical characterization of the Vega Baja del Segura region is been conducted as a part of the Spanish funded project EVITA2. The main goal of EVITA2 is to develop a prototype of an integrated tool to map seismic hazard scenarios at regional and local scales. Located SE Iberian Peninsula, in the low Segura River, the Vega Baja can be considered at present as a moderate earthquake activity region although a number of destructive earthquakes have occurred in the past. Both the very recent rapid growth of urban developments together with the specific peculiarities of soil condition in the area have greatly increased seismic risk.

We use digital geological cartography and surface geology together with geotechnical data (170 boreholes of which 130 incorporate in situ and laboratory tests) as collected from public and private sources and complemented with data in the available literature. Two field surveys of ambient noise recordings were conducted for S-wave velocity profiling and Horizontal-to-vertical spectra ratios (HVSR) analysis.

Geological, geotechnical and geophysical geo-referenced data and information are merged in a common relational database fully compatible with GIS tools, which enables to have a complete data control by means of logical relationships.

Based on this comprehensive geo-database compiled for the area, the analysis of site effects including ground motion amplification and liquefaction potential for different scenario earthquakes is carried out.

### GROUND MOTION SCENARIOS FOR ENGINEERING APPLICATIONS: THE CASE OF THESSALONIKI, GREECE – ID 1817

*G. Ameri, INGV, Italy*
*G. Cultrera, INGV, Italy*
*G. Franceschina, INGV, Italy*
*F. Pacor, INGV, Italy*
*A. Akinci, INGV, Italy*

*A. M. Lombardi, INGV, Italy*
*V. Pessina, INGV, Italy*
*G. Zonno, INGV, Italy*
*M. Cocco, INGV, Italy*

Within the framework of the European integrated project "LESSLOSS – Risk Mitigation for Earthquakes and Landslides", two sub-projects are devoted to earthquake disaster scenario predictions and loss modelling for urban areas and infrastructures. The overall aim is to provide strong quantified statements to support decision-making for seismic risk mitigation strategies. We present the ground motion scenarios estimated for the city of Thessaloniki, Greece, in the frequency band of engineering interest (up to 20 Hz). We adopted finite fault methods to simulate acceleration/velocity/displacement time series. Two techniques were used: the deterministic-stochastic simulation technique, DSM (Pacor et al., 2005) for the high frequencies (f>0.5-1Hz) and COMPSYN (Spudich & Xu, 2002) at low frequencies (f<2.5 Hz). To calibrate some kinematic parameters of the rupture process and the crustal velocity model we simulated the 20 June 1978 Thessaloniki earthquake (Mw=6.5) and we compared the results with the accelerometric record of the event at the Thessaloniki city-hotel station. On the basis of recent seismotectonic studies four faults have been recognized as possible active sources in the area near Thessaloniki with a moment magnitude from 5.9 to 6.5. We generated ground motion time series on a regular grid covering the urban area, for a total number of eight scenarios. The PGA in the urban area, varies from 0.06 - 0.6 g depending on the selected scenario. The synthetic results have been then compared with different ground motion predictive equations for peak values and response spectra 5% damped. The simulated acceleration and velocity peaks are inside the mean ± 1 standard deviation predicted by the attenuation relationships. However, the simulated peaks of displacement can not be compared with the attenuation relation due to the lack of high quality empirical data; moreover the synthetics present more complicated features related to the influence of radiation pattern distribution.

### THE ATTENUATION OF SEISMIC INTENSITY IN ITALY: THEORETICAL AND EMPIRICAL BACKGROUNDS – ID 1856

*C. Pasolini, Dip. di Fisica, Univ. di Bologna, Italy*
*P. Gasperini, Dip. di Fisica, Univ. di Bologna, Italy*
*D. Albarello, Dip. Sc. della Terra, Univ. di Siena, Italy*
*B. Lolli, Dip. di Fisica, Univ. di Bologna, Italy*
*V. D'Amico, Dip. Sc. della Terra, Univ. di Siena, Italy*

We critically analyzed the results of previous studies on seismic intensity attenuation in Italy performed by some of us. Although no mistakes were made in such works, we demonstrate here that they do not reproduce the real behavior of seismic intensity with distance from the source due to the inadequacy of some of the assumption made. We also propose some recipes that can be useful to obtain unbiased estimates of the attenuation properties and also significantly improve the goodness of fit with data: 1) Intensity data located at distances from the source for which an intensity value below the limit of diffuse perceptibility (about IV) is expected makes the resulting attenuation function to overestimate intensity at large distances. Thus, for an unbiased estimate, such data have to be excluded from computations. 2) Epicentral intensities Io reported by the Italian catalog (computed as the maximum observed one or little less when site amplification was supposed to occur) overestimates the intensity predicted by attenuation laws at the epicenter of about one intensity degree on average and then need to be recomputed consistently. 3) A possible way to make epicentral intensity consistent with the intensity expected at the epicenter is to define it as Io=Iav-g(h)+g(Dav) where g(x) is the functional representing the distance dependence of seismic intensity, h the source depth, Iav and Dav respectively the averages of the observed intensities and the epicentral distances, computed over all intensity data of each earthquake. The application of these recipes to the same dataset used in previous studies decreases the model residual mean square of more than 30%.

## SC-F 5: Seismic Hazard and Risk due to Induced Seismicity

Level 2

### SEISMIC MONITORING OF AN UNDERGROUND NUCLEAR WASTE REPOSITORY AT OLKILUOTO, FINLAND – ID 41

*J. Saari, Enprima Ltd, Finland*

The island of Olkiluoto, in the western coast of Finland, has been selected as the site for the final disposal facility of spent nuclear fuel. A Finnish expert organisation, Posiva runs there a seismic network of eight seismic stations. All sensors are at the surface of the island surrounding the preliminary location of the final disposal facility.

Posiva started to construct an underground characterisation facility in Olkiluoto, in 2004. This facility will be used to acquire detailed information about the bedrock in Olkiluoto, to be utilised in the planning of the final disposal facility. The construction of the actual final disposal facility is scheduled to start in the 2010s, and the final disposal of spent nuclear fuel can be started in 2020.

The microearthquake measurements in Olkiluoto aim for better understanding of the structure, behaviour and long-term stability of the bedrock. The above mentioned construction works will change the characteristics (e.g. the stress field) of the virgin bedrock. Those changes will produce microearthquakes. The observed seismic events give an opportunity to approximate in what extent and where the bedrock is disturbed.

Identification of active fracture zones is an essential element in a comprehensive study of potential hazards related to the spent nuclear fuel. The zones of weakness adjust releasing stresses and strains of the rock mass as well as they are the main paths of hydraulic flow in the bedrock. The movements occurring on these zones accumulate during the lifespan of the repository and possibly can cause changes in the stability, stress field and groundwater conditions of the rock mass. The interpretation can bring out information that will be used for model calibration and even further cause changes to final disposal facility layout.

In this presentation, the seismic monitoring project and preliminary results are introduced.

### THE STUDY OF INDUCED SEISMICITY IN THE AREA OF AZAT DAM IN ARMENIA – ID 531

*V. Hayrapeyan, National Survey for Seismic Protection, Armenia*
*V. Khondkaryan, National Survey for Seismic Protection, Armenia*

The seismicity of the area of reservoir ( r = 20km) was studied in Armenia's seismoactive region having an aim to discover the possible spatial and temporal changes of background seismicity. The existence of dense and "sensitive" seismic network allows to locate the epicenters of relatively weak earthquakes ( 1.8 <M< 2.5) that occurred in the area under study. This is the attempt to reveal peculiarities of background seismicity and correlation that may exists between the seismicity and the changes of water level in reservoir. On the bases of histogram analyze of weak earthquakes quantity it was concluded the dependence of area's seismicity on reservoir's level.

### ACCELERATION RESPONSE SPECTRA FROM MINING TREMORS – ID 665

*K. Kuzniar, Pedagogical University of Cracow, Poland*
*E. Maciag, Cracow University of Technology, Poland*
*T. Tatara, Cracow University of Technology, Poland*

In Poland, in Legnica-Glogow Copperfield (LGC) mining rockbursts excite tremors characterized by energies run to 1E10 J and surface vibrations which intensity reach even 0.3g (g - acceleration of gravity).

Mining exploitation is mainly carried out under urbanized areas and heavily populated, so, the problem of acting mining – related surface vibrations is particularly important. The comparison of ground mining – related vibrations with earthquake ones will be presented. Buildings in LGC have not been designed for seismic forces. Acceleration response spectra are applied to characterize surface vibrations and can be used in design procedure of new structures as well as for estimation of harmfulness of vibrations for real buildings. It only refers to elastic response spectra – comp. Eurocode 8, because in LGC several the most intensive events may yearly occur. The accelerograms acquired in seismic stations placed in LGC have been applied to prepare acceleration response spectra. They have been calculated on the basis of ground and basement vibrations of low rise, 5 and 12 storey buildings. The spectra were worked out with the fraction of critical damping.

Similarities and differences between the response spectra from ground and basement vibrations are shown. The second ones are more useful for estimation of mining tremors harmfulness to actual buildings. The response spectra from ground vibrations were compared with elastic response spectrum given in Eurocode 8.

Artificial Neural Networks were applied to determine the relation between above mentioned response spectra. In order to design appropriate neural networks the sub-picture idea from picture transmission was also adapted. The response spectrum from the vibrations recorded on the ground was neurally mapped into the corresponding value of response spectrum from the vibrations recorded at the same time on the building basement level.

## INDUCED SEISMICITY WITHIN EXPLOITED HYDROTHERMAL FIELDS IN KAMCHATKA (RUSSIA) – ID 734

*Y. Kugaenko, Kamchatkan Branch, Geophysical Survey, RAS, Russian Federation*

Hydrothermal fields suitable for electric power production, are located in the areas of high geodynamic, volcanic and seismic activity. Level of seismic hazard and risk in these areas can increase unpredictably due to man-made activity by geothermal energy extraction. In given report data about seismicity in areas of high-temperature exploited Pauzhetsky and Mutnovsky hydrothermal fields (Kamchatka) are shown. Three geothermal power plants (Pauzhetsky, 11 MW, Verkhne-Mutnovsky, 12 MW and Mutnovsky, 50 MW) began to work here in 1967, 1999 and 2002 accordingly. By data of Kamchatkan regional seismic network it was shown that after the exploitation start, shallow earthquakes were registered directly from exploited zones. But earlier it was presumed that local seismicity is absent in these areas. Some of earthquakes in Pauzhetsky hydrothermal field were sensible without damage of buildings and wells. Ground motions had intensity about 6. Activization began 6 years after exploitation start. It is first example of induced seismicity appearance in hydrothermal field in Russia. In Mutnovsky hydrothermal field first earthquakes from exploited area were recorded by Kamchatkan regional seismic network in 1996. Intensive deposit exploitation changes reservoir pressure; parameters and state of hydroterms and internal conditions of upper crust and it can be the reason of inducted seismicity. In the report some phenomena connected with Mutnovsky geothermal field exploitation are present. It is seismic events, temporal changes of wells parameters, hydrothermal explosion and appearance of new surface hydrothermal manifestation. For estimation of additional seismic hazard caused by industrial activity it is necessary to collect and summarize information about seismic activizations in hydrothermal fields by worldwide data. It can include the description of hydrothermal field, induced seismisity parameters, examples of seismic records. Preliminary structure of database is shown in presentation. Previously it is advisably to enlist the support by International Geothermal Association for this problem solving.

## FIELD DATA AND LABORATORY MODEL ON CONTROLLING INFLUENCE OF WATER LEVEL PERIODIC VARIATIONS IN A LARGE DAM – ID 934

*T. Matcharashvili, Institute of Geophysics, Georgia*
*T. Chelidze, Institute of Geophysics, Georgia*
*O. Lursmanashvili, Institute of Geophysics, Georgia*
*Z. Javakhishvili, Institute of Geophysics, Georgia*
*M. Devidze, Institute of Geophysics, Georgia*
*T. Khutsishvili, Institute of Geophysics, Georgia*

We present an evidence for reservoir-induced controlling influence of water level periodic changes in Enguri high dam reservoir (located in western Georgia) on regional seismic activity. In the present research the data sets of water level daily variations in the Enguri high dam reservoir and the seismic data sets recorded by the local network have been analysed. Moreover laboratory acoustic emission data obtained during stick-slip experiments with superimposed weak periodic perturbations have been also been investigated as a model of natural seismicity. Methods of linear, nonlinear and phase synchronization analysis have been used to field and laboratory data in order to obtain quantitative assessment of possible controling influence of external periodic influence on investigated real and model data systems. It is shown that under the influence of a large water reservoir, regional seismic activity increases according to the well-known concepts of reservoir-induced seismicity. Initially, reservoir-induced increase in regional seismic activity is observed, but when the variation of the water level in the reservoir becomes periodic, the released energy value essentially decreases. Using above mentioned methods as well as recurrence quantitiative analysis (RQA) approach on laboratory data sets it was shown that under weak external periodic influence amplitude and temporal distributions of acoustic events may be controlled. Namely depending on character of external influence sufficient decrease of amplitudes and time interval of acoustic signal might be kept in a lower range comparing to situation without external influence. Dynamical changes relevant to increase of regularity of acoastic emission process under peridic influence is evident. According to our results we conclude that decrease in daily seismic energy release around Enguri high dam during water level periodic variation may be assumed as a control of seismic activity imposed by weak periodic changes of water level in the reservoir.

## EVIDENCE FOR REAL-TIME CORRELATION OF MINING ACTIVITY AND INDUCED EARTHQUAKES IN PARNASSOS MINE (GREECE) – ID 1625

*V. Chrisanthi, Aristotle University of Thessaloniki, Greece*
*C. Papazachos, Aristotle University of Thessaloniki, Greece*
*D. Vamvakaris, Aristotle University of Thessaloniki, Greece*
*I. Dimitriadis, Aristotle University of Thessaloniki, Greece*
*A. Karamesinis, Aristotle University of Thessaloniki, Greece*

A study of the microearthquake activity observed at the Kaniani-Parnassos mines has performed in order to determine the origin of the several "unknown" shocks observed at the area of the mine. Preliminary analysis of recordings indicated that the shocks were of tectonic origin. A portable network of three accelerographs (located inside the mine-no absolute time) and five three-component digital seismographs (located in surface locations on top of the mine-absolute time) were installed for a period of nine months. The analysis of impulsive, high frequency (>20 Hz), short duration (2-3 sec) recordings, showed that the observed seismicity is of very local scale, located at a specific section of the mine. The microseismic activity exhibited a very strong time-correlation with the exploitation level, as this is revealed from the very significant variation of the earthquake rate of occurrence after the start of the operation of the mine, as well as the clear coupling on the rate of microearthquake occurrence with the rate of mining explosions. The focal mechanisms of the ruptures and the local stress field were evaluated using the first arrivals of the P-waves along with the P/S spectral ratios. The focal mechanisms are all of thrust type, indicating reverse ruptures caused by a compressional stress field with ESE-WSW direction. This field is almost perpendicular to the strike of the local old syncline-anticline, where the mine deposit is located; hence it can be safely assumed that is the "remnant" stress field that created this compressional mega-structure. The determined ruptures are in excellent agreement with the main tectonic discontinuities mapped inside the mine. A typical dynamic stress drop of 10-20 bars was also calculated for the biggest events

(M 1.0) which is relatevely comparample with the typical expected value of the mean effective isotropic stress ( 50 bars).

### MINING INDUCED SEISMICITY AND ROCK-MASS VELOCITY HETEROGENEITIES – ID 1664

*W. Debski, Institute of Geophysics PAS, Poland*

Mining induced seismicity tends to cluster in both space and time. While the temporal clustering can be connected to mining activity the question of spatial clustering is more complicated. In this case there are two factors that have to be taken into account, namely the mining activity and rock-mass heterogeneities. In this contribution an attempt is taken to relate the induced seismicity to the rock mass heterogeneities as measured by passive seismic tomography. To make this analysis as robust as possible the advanced tomography imaging based on the Monte Carlo sampling technique is used. The preliminary analysis of the seismicity from the Rudna copper mine (Poland) does not show a simple relation. While two large seismic clusters occurred in an area of high velocity gradients we also noticed the seismic activity in the region of an increased velocity. This preliminary observation has still to be confirmed by a more detailed analysis.

### SEISMICITY IN NW-GERMANY: INDUCED BY GAS-EXPLOITATION OR NATURAL TECTONIC ORIGIN – ID 1697

*K. Klinge, BGR / SZGRF, Germany*
*K. Stammler, BGR / SZGRF, Germany*
*T. Dahm, University, Germany*
*F. Krueger, University, Germany*
*R. Kind, GFZ, Germany*
*T. Plenefisch, BGR / SZGRF, Germany*
*K. Wylegalla, GFZ, Germany*

The Central Seismological Observatory Graefenberg (SZ-GRF), a part of the Federal Institute of Geosciences and Resources (BGR), is the data centre for the German permanent digital broad-band stations. It's main task is the observation and interpretation of local, regional and global seismicity. Within the last ten years we observed an increasing number of moderate magnitude earthquakes in a previously aseismic region in the NW-German sedimentary basin. Especially, the October 20, 2004, Mw = 4.4 earthquake was studied in more detail and a possible relationship between this event, the tectonic setting and the local gas exploitation was investigated. We determined the source parameters by different waveform inversions and modelling approaches. The event occurred within a few kilometres from major gas production fields and the source depth of the main shock was constrained between 5 and 7 km. The instrumentally determined source depth and the comparison with triggered seismicity in the Northern Netherlands gas fields suggests that this event may be related to local gas recovery.

### ENERGY DISTRIBUTION OF SEISMIC EVENTS FROM THE UPPER SILESIAN COAL BASIN, POLAND – ID 1797

*A. F. Idziak, University of Silesia, Faculty of Earth Sciences, Poland*
*J. Hollek-Idziak, University of Silesia, Faculty of Earth Sciences, Poland*
*L. Rudzinski, Inst. of Geophysics Polish Academy of Sci., Poland*

Most seismic events observed in Polish part of the Upper Silesian Coal Basin have seismic energy between 100 J and 10 GJ Weak events are induced by mining activity and they occur near excavations. The strong events result from mutual interactions among mining and tectonic stresses. It is possible to construct theoretical distributions for low-energy events and stronger events separately but there is no way to approximate obtained data by unimodal distribution in the wide energy interval. The aim of the present work was to approximate the high - energy mode of seismic events occurring in the USCB by theoretical distribution. To study energy distribution of strong shocks, the seismic catalogue containing 17,608 events of energy not less than 100 kJ registered during the period 1987-2004 was used. The theory of extreme values can be applied to seismic event catalogues, which are often incomplete, especially at the low-energy range. According to Gumbel there are only three distributions asymptotically convergent to the exact distribution of extremes. Analysis of the data set showed that the empirical cumulative distributions could be fitted by Gumbel's II distributions: Earlier studies of energy distribution, which were done using a less numerous catalogue, showed the threshold energy of high-energy mode approximately between 1 MJ and 10 MJ. The better accuracy of the present study allowed to establish the energy limit about 80,000 J. The similar analysis, carried out for weak events recorded in a mine operating in the most seismically active subunit of the USCB, showed that their energy distribution could also be approximated by Gumbel's II distribution with threshold energy being about 100 J. This suggests that mechanisms generating weak and strong events are similar but they act in different scales. It seems, that, the model assuming two different weakly interacting seismic processes might be applied for the USCB.

### HOW TO MODEL SEISMIC LOADS FROM ROCK-BURST INDUCED GROUND MOTION – ID 1799

*Z. Zembaty, Opole University of Technology, Poland*

Deep mining often takes place near or below habited areas. The rockbursts generate then surface ground motion similar to small earthquakes causing damages to buildings and equipment (e.g. Knoll 1992). The research on the nature of surface effects from rockbursts in the copper basin LGOM in Poland revealed two characteristic patterns of the generated surface ground motion (Zembaty 2004): Events of type which occur quite often (return period 3-6 months), with very short duration (1-2s) and high frequency spectral content, similar to surface blast effects. Events of type II occurring rather rarely (e.g. once in 5-10 years), with longer duration and low frequency content similar to small, shallow earthquakes. This classification, based on the surface ground motion characteristics, is similar to the one proposed earlier by Jonston (1992) which took into account the seismological and technological rockburst description. Each type of the ground motion causes different structural effects and requires different approach in mitigating the resulting damages. A detailed analysis of ground motion parameters assessed from extended network of surface accelerometers will be the subject of the presentation planned for the ECEES 2006 Conference. It will summarize both earlier research by the author (Zembaty 2004) and will present new results regarding modeling these effects for the design of structures in the vicinity of mines. References Johnston J.C., Rockbursts from a global perspective, in: Induced Seismicity, edited by Knoll P., Balkema, Rotterdam, Brookfield, 1992, pp.63-78 Knoll P., editor, Induced Seismicity, Balkema, Rotterdam, Brookfield, 1992 Zembaty, Z., Rocburst induced ground motion – a comparative study, Soil Dynamics & Earthquake Engineering, 24 , 2004, pp.11-23

### EARTHQUAKES IN NORTHERN GERMANY: TECTONIC AND INDUCED – ID 1834

*G. Leydecker, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*D. Kaiser, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*H. Busche, Fed. Inst. f. Geosci. and Nat. Resources, Germany*
*T. Schmitt, Fed. Inst. f. Geosci. and Nat. Resources, Germany*

The seismicity of the lowlands in Northern Germany is very low. From the history since the year 800, no damaging earthquake is known there. The earthquakes in this region are of different origin: tectonic events, natural collapses below salt domes, induced events in a coal mining area and in connection with the production of natural gas.

The earthquakes of tectonic origin are rare and only few are observed. The subsidence events in the city of Hamburg are connected with a salt dome, whose top in a depth of 80 m reaches into the groundwater stream. The earthquakes in the coal mining area must be seen as a consequence of local stress field changes caused by min-

ing processes.

In the lowlands of Northern Germany a lot of gas and some oil fields are under production. The gas deposits are of different sizes and in different depths, from 2.5 km to 5 km with a thickness of 0.5 to 1 km. The gas extraction strongly reduces the internal forces and it may come to a sudden dislocation of the overlaying stratum or inside the gas reservoir. The earthquakes are of normal faulting, as fault plane solutions show. Due to their shallow depths, also small events of magnitude ML 2 to 3 are felt strongly, accompanied with loud sounds in the epicentral area. For example, the earthquake in 2002 south of Bremen with ML = 2.3 and epicentral intensity of V EMS was felt 5 km around the epicentre. The only explanation for this is a shallow focal depth and an induced event related to the gas production out of a depth of 3 km. For some events, the origin if tectonic or induced is not clear. This is of particular importance for the largest event (ML=4.5) that occurred in 2004 near Rotenburg (Wümme).

## HAZARD ASSESSMENT AND SEISMIC RISK REDUCTION IN ROCK REMOVAL BLASTS ON SITE OF CERNAVODA LOCK OF DANUBE-BLACK SEA CANAL – ID 1839

*A. Pantea, National Institute for Earth Physics, Romania*
*A. Constantin, National Institute for Earth Physics, Romania*
*V. Marza, University of Brasilia, Brazil*

Explosion technologies have been used to clear rocks for building the Danube-Black Sea canal, especially the Cernavoda lock. To pave the way for using such technologies, research had to be carried out to ensure antiseismic protection of vital systems and buildings either existing or under construction in proximity of the canal. The main goal of the research was to assess the hazard and cut down the seismic risk entailed by rock removal blasts. The studies were aimed at providing antiseismic protection of the exposed parts of the highway, embankment, railroads, overhead power lines, etc., and at controlling and mitigating blast effects on the final walls of the excavation by minimizing the area where the break occurs and radial cracks are generated (Pantea, 1976; Pantea & Marza, 1976). Moreover, the blast technology used for digging the site of Cernavoda lock posed the threat that banks might crumble and crash on the railroad or that railroad embankment might collapse. There was also the danger of 'bombardment' as blast gas pressure could have projected rocks into the air, which could have shelled the railroad embankment, power lines or trains standing or rolling in the area. The resulting seismic data consisted of seismograms which were processed to provide the main dynamic parameters of seismic oscillations (displacements, velocities, frequencies, etc.) arising in the ground as a result of blasts.

## MONITORING OF INDUCED MICROEARTHQUAKES FOR IMPROVED SEISMIC RISK ESTIMATES – ID 1840

*V. Oye, NORSAR, Norway*
*M. Roth, NORSAR, Norway*
*C. Lindholm, NORSAR, Norway*

The occurrence of microearthquakes in hydrocarbon reservoirs, geothermal energy sites and mining areas is often related to human activities. Production as well as gas and fluid injection for production stimulation are measures that influence the state of stress in the reservoir and may result in stress redistribution in terms of microearthquakes. Likewise, stress changes due to excavations during mining induce microearthquakes.

Within the last six years, NORSAR has developed software for automatic event detection, localization and determination of microearthquake source parameters like e.g. seismic moment, corner frequency, radiated seismic energy and stress drop. The basic processing routines include event association, P- and S-wave onset time picking, polarization analysis and localization methods for homogeneous as well as for 3D velocity models. The processing results are stored in a database from which bulletins can be produced. To get a better understanding of the seismic activity in the investigation area, we included an interactive 3D visualization of the microearthquakes within a 3D reservoir/mine model. The various event attributes can be coded in size, color, shape and transparency and movies improve the understanding of the time-dependency of the microearthquakes, spatial migration, systematic magnitude changes, etc.

In the mining industry, such seismic monitoring systems are well-established (in some countries even law-enforced) and they are used for the purpose of hazard mitigation and production optimization. We present an example of microearthquake monitoring in an oil-field and in an active ore mine. The spatio-temporal event distribution as well as the size of the events provide relevant insights about the production related seismic activity.

## HAZARD ASSESSMENT AND SEISMIC RISK REDUCTION IN ROCK REMOVAL BLASTS AT ARNOTA (ROMANIA) LIMESTONE QUARRY – ID 1841

*A. Pantea, National Institute for Earth Physics, Romania*
*A. Constantin, National Institute for Earth Physics, Romania*
*V. Marza, University of Brasilia, Brazil*

A research was conducted to ensure antiseismic protection of the building structure and architectonic elements and murals at Arnota Monastery, a historical and religious monument. Antiseismic protection was based on hazard assessment and seismic risk reduction in the circumstances of rock removal blasts at a limestone quarry near the monastery. To ensure antiseismic protection of various structures (by preventing potential deterioration) and minimize damage claims, especially in heavily populated areas, mining businesses can cut seismic oscillations caused by rock removal blasts down to admitted values. To this end, various safety limits have been set for the maximum displacement and oscillation frequency of a ground particle. The instrumental seismic data resulting from the Arnota research consisted of seismograms on which the three seismic movement components had been recorded. A processing of these data supplied the main dynamic parameters (displacements, velocities, frequencies, etc.) of the blast-caused seismic oscillations arising in the ground.

## NONPARAMETRIC ESTIMATION OF THE PROBABILISTIC CHARACTERISTICS OF MINING INDUCED SEISMIC SOURCES FROM THE UPPER SILESIAN COAL BASIN, IN POLAND – ID 1883

*S. Lasocki, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*
*B. Orlecka-Sikora, AGH, Faculty of Geology, Geophysics and Env. Prot., Poland*

The Upper Silesian Coal Basin (USCB) in Poland is an area of high level of mining induced seismic activity. The analysis of seismic catalogues from the coal mines located in USCB showed that seismic events form 35 space-time zones of seismicity. Each of the zones is characterized by its own seismic potential. This potential is represented by probability distribution functions of magnitude, out of which the cumulative distribution function (CDF) is of primary importance in hazard studies. The magnitude distribution of mining induced events is multimodal therefore the CDF was estimated by a model-free, nonparametric estimator. The 95 per-cent confidence intervals of CDF were calculated using resampling methods based algorithm, the iterated bias corrected and accelerated method (iterated BCa method). For the seismic zones characterized by the highest potential to generate strong events the confidence intervals of other probabilistic descriptors of the seismic sources, viz. the exceedance probability of a given magnitude in a specified time period D and the mean return period of events of a given magnitude were estimated. Mapping of the estimates of the upper limit of magnitude for the particular seismic zones provided useful information regarding distribution of the seismic potential over the USCB area. The potential is high in a central belt which intersects the area from NW to SE and decreases towards both margins of this belt.

### ATTENUATION RELATION FOR PEAK GROUND ACCELERATION AND SPECTRAL AMPLITUDES OF GROUND MOTION CAUSED BY MINING INDUCED SEISMIC EVENTS – ID 1937

*D. Olszewska, AGH University of Science and Technology, Poland*
*S. Lasocki, AGH University of Science and Technology, Poland*

Equations for predicting the horizontal peak ground acceleration and spectral amplitudes of ground motion caused by mining induced events from Legnica Glogow Copper District in Poland are presented. Underground exploitation of the copper ore deposit in this area is accompanied by intensive seismic activity. The seismic sources occur at shallow depths, therefore, despite the events are weak, their ground effects can be significant and damaging. Ground motions of the peak acceleration exceeding 0.1 are not exceptional in the urbanized parts of this area. We analyzed acceleration signals from 14 recording stations. The signals were parameterized by the horizontal peak ground acceleration of ground motion and larger of two horizontal components of 5% damped acceleration response spectra for periods from 0.1 to 1 s. The final attenuation relations were tested statistically and confidence intervals for prediction were also determined.

## SC-G 0: Rapid Intervention Field Investigation Teams (Open Session – Posters Only)

Level 2

### FIELD SURVEYS IN ITALY: THE QUEST EXPERIENCE – ID 88

*A. Tertulliani, INGV, Italy*
*Quest Team, INGV, Italy*

The acronym QUEST hides the sentence Quick Earthquake Survey Team, an idea arisen after the 1997 Umbria-Marche seismic sequence, and slowly become a project in the first years of the new millennium. The starting aim was to assemble "Italian macroseismic people" in a unique task force that, in case of significant earthquakes, could be organized and ready to go in a short span of time. Of course, it was not easy to get the agreement of different people with their experiences and methodology, but some result has been yielded. Now QUEST is almost entirely formed by INGV personnel, with the exception of some people coming from University of Basilicata and Italian Civil Protection Department. About twenty people alternatively participate to the surveys, in dependence of the earthquake size, the epicentral location and the personal availability. Our “reaction time”, for Italian earthquakes (alerted by a SMS from INGV automatic location system), is very fast: in about two hours we are able to organize the preliminary survey. In the period 2002-2005 Quest conducted 8 reconnaissance surveys for (luckily) moderate events. During the survey the field teams are coordinated by a central bureau that updates the intensity map in real time, keeps contacts with authorities and disseminates (if it is possible) the data by internet. Last experience of Quest was EUROT2005, an international training operation of a simulated earthquake in Sicily, during which Quest checked its coordination and communication system.

### TRACES THROUGH THE MACROSEISMIC FIELD EXPERIENCE IN BULGARIA – ID 584

*R. Glavcheva, Geophysical Institute, Bulgaria*
*S. Dimova, JRC, Italy*
*B. Ranguelov, Geophysical Institute, Bulgaria*
*N. Cecic, ARSO, Slovenia*

This study briefly reviews the approach of organizing macroseismic investigation in Bulgaria in the course of time, after the national seismological service has been established. The present-day macroseismic practice is traced along its complete path and important issues are pointed out. The survey field methodology (methodology of data collection) currently in use is presented based on practical examples. Our experience proves that seismologists, earthquake engineers and geologists complement each other in the macroseismic field teams. Some examples of the fast data collection and assessment and the reinterpretation of the macroseismic data and reprocessing information are presented. Most practical issues about the use for the purposes of seismic hazard assessment of the different structures have been illustrated.

### POST- EARTHQUAKE EMERGENCY INSPECTIONS AND ASSESSMENT OF BUILDING SAFETY – ID 1236

*S. Anagnostopoulos, University of Patras, Greece*
*M. Moretti, University of Thessaly, Greece*

In this paper the key technical and organizational issues associated with post-earthquake emergency inspections of building damage, assessment of their safety and emergency interventions are presented and recommendations are made based on extensive experience from past earthquakes. Safety and usability criteria are established and correlations with various damage states are given, along with detailed rules of damage assessment for reinforced concrete and masonry buildings. The damage states of various structural as well as non-structural elements are described and quantified and rules are provided for assessing the overall safety of a building based on the severity and extent of damage of its elements. All the necessary information for reaching objective damage and building safety assessments as well as other pertinent data is recorded in a carefully detailed Damage Inspection Form, which is a basic tool for the engineers – inspectors. Organizational, logistical and legal issues that may arise in such operations are also presented and pertinent recommendations are made. The procedures and tools given herein aim at providing the framework for organizing such operations effectively and bringing them to successful completion under the conditions of emergency created by the earthquake. The key objectives are to save human life first and property second and to minimize the number of homeless by providing the assurance people need for the safe re-occupation and use of their homes and work places.

### FITESC BLOG – ID 1658

*I. Cecic, ARSO, Slovenia*

FITESC (Field Investigation Team of ESC) opened a blog (fitesc.blog.hr) in September 2005, providing a new possibility for fast exchange of intensity data after a strong and damaging event in Europe and the Mediterrannean region. Today (April 2006) the blog consists of 17 entries, giving information about 8 earthquakes (5 in 2005 and 3 in 2006). The entries are either first available press reports about the situation in the epicentral area, or (as in the case of 8 Jan 2006, Kythira, Greece earthquake) preliminary intensity estimations collected in different countries for a particular event. A paper about explosions is posted as well. As the blog server experienced some problems recently, it is planned to move the blog on another server in the following months.

### A GIS UTILITY FOR MANAGING MACROSEISMIC INTENSITY DATA – ID 1932

*R. Azzaro, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*S. D'Amico, Istituto Nazionale di Geofisica e Vulcanologia, Italy*
*T. Tuvè, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

One of the problems in macroseismic surveying is the management of collected data during field activities. Basing on the potential of GIS tools, we compiled a MapBasic program for MapInfo ® that quickly and easily generates intensity tables and related maps. The tool uses a geographic directory containing all the Italian settlements (cities, towns, villages and other localities), so that the user chooses the locality from the map view, excluding any possibility of errors due to the coincidence of names, and assigns the intensity value. The user, by the "visual" insertion

of the site intensity, is able to make a macroseismic field map in near-real time as the field teams send their data. When the map is completed, the program automatically runs codified routines to calculate the main parameters of the earthquake (macroseismic epicentre, fault dimension, etc.). Then it creates the tables with the records formatted to update the database of the macroseismic observations and the associated parametric catalogue. The routine is totally integrated in the MapInfo environment and may be used in maps containing other geographic information generally used by GIS software. This utility may be a useful tool not only for new macroseismic investigations but also for reviews of historical earthquakes.

## SC-G 2: Recent Macroseismic Field Surveys

Level 2

### THE REVALUATION OF THE MACROSEISMIC EFFECTS OF MARCH 4, 1977 MAJOR VRANCEA EARTHQUAKE. – ID 1946

*A. Pantea, National Institute for Earth Physics, Romania*
*A. Constantin, National Institute for Earth Physics, Romania*

In the past time the macroseismic intensity was an important parameter for the quatification of the Romanian territory seismic activity. The strongest and the best known, from the point of view of the macroseismic effects, is the March 4, 1977 earthquake (MGR = 7.2 and Imax = IX), occurred in Vrancea seismogenic zone. The earthquake was a multiple event, consisting of a foreshock and at least 3 main shocks. The third main shock which was the strongest one of the earthquake, occurred 19 sec after and at a horizontal distance of 62 km from the foreshock. The main purpose of reevaluation of the macroseismic effects of the March 4, 1977 major earthquake, is, on the one hand, to eliminate the existing suspicions regarding the veracity of evaluating the macroseismic effects by the romanian seismologists at that time, and, on the other hand, to take out some of the uncertainties that have appeared during the process of evaluation, processing and interpretation of the macroseismic data.

## SS 3: Education and Outreach for Risk Reduction

Level 2

### DEVELOPMENT OF A SIMPLE SEISMOGRAPH FOR EDUCATION OF DISASTER PREVENTION – ID 1218

*T. Sawamatsu, Hiroshima University, Japan*
*K. Ichii, Hiroshima University, Japan*
*T. Tanaka, Musashino Institute of Technology, Japan*
*T. Tsuchida, Hiroshima University, Japan*

Earthquakes are one of the major natural disasters which cause disastrous consequences on human life, property, and infrastructure. Although the occurrence of these earthquake-induced disasters can not be prevented completely, the extent of damage can be lessened through proper awareness programmes for people. For the implementation of the programmes, it is important and effective to conduct disaster prevention programmes at school levels. Engineers and researchers should be involved in these programs since they have knowledge on the mechanisms of these disasters.

A pendulum type seismograph that someone can make easily and cheaply by available material in kitchen was developed for awareness progmammes. A magnet was installed in the seismograph as the weight of the pendulum. The orbit of relative displacement between ground and the weight by an earthquake motion can be recorded with the magnetic forces between the magnet and iron powders. It is applicable not only in recording orbits of relative displacement, but also for the estimation of seismic intensity. Based on the consideration of response spectrum characteristics of the motion, the methodology for determining a set of concentric circles to evaluate the seismic intensity by the orbit was proposed in the paper.

The development of this simple seismograph may assist children to have an interest on earthquakes. Furthermore this simple method can be widely installed even in the developing countries due to its cheapness, and a seismic network can be constructed.

### EDUCATION AND INFORMATION AS TOOL FOR RISK MITIGATION: THE EXPERIENCE OF THE EOLIAN VISITORS CENTRES – ID 1396

*R. Nave, INGV OV, Italy*
*C. Piccione, INGV, Italy*

Stromboli and Vulcano: two operational centres of the National Institute of Geophysics and Volcanology (INGV) involved in educational activity on volcanic risk since many years. This activity has two aims: - to inform thousands people that each year visit the Eolian Islands attracted by the two active volcanoes; - to provide resident communities with correct information useful to learn how to live with an active volcano. Educational and outreach activity carried out by the Stromboli and Vulcano INGV centres is the most efficient answer to the huge information request both by tourists and resident people. Besides the possibility to find educational and informational material on the two volcanoes also on multimedia support, the INGV centres give the opportunity to learn more on how the permanent monitoring system works and how data recorded are transmitted and elaborated in real time. The output of the educational path set up in the two centres, is the improving of visitors awareness of the real hazard and risk linked to the two volcanoes, and their present state. All that output will a promote a conscious a more suitable behaviour both in facing the excursion to the crater, and in contributing to risk mitigation also in case of emergency. Data published recently by Regional Tourism Agency of the Eolian Islands confirm the great increasing of visitors during the summer months: each year an average of 20.000 people climb to Vulcano crater, and about 13.000 are interested in field excursions to the Stromboli summit craters, accompanied by expert guides for safety reason. The visitors data analysis shows also the increasing schools for the educational activity carried out in the two INGV centres, often inserted in the formal learning activity as an occasion to go into Earth Science themes.

### LEST WE FORGET. A PRELIMINARY MAP OF THE COLLECTIVE EARTHQUAKE RITUALS OF ITALY – ID 1410

*V. Castelli, Istituto Nazionale di Geofisica e Vulcanologia, Italy*

Fear and the need for reassurance - feelings as old as humankind - find cultural expression in countless visible ways: beliefs and behaviour patterns, rules and rituals, good and bad habits. However, there is also an invisible "non-way" to express them, by dismissing from the mind and forgetting as soon as possible whatever it was that made us afraid and needing reassurance. In the case of communities living in "earthquake country" this kind of reaction does seems a predictable, indeed almost an obligated one: how could people go on living in places that were repeatedly and tragically affected by seismic disasters, unless by getting used quickly to forget the worst of their past sufferings? But is the tendency to remove and forget an hereditary trait of humankind, or the results of specific stimuli (more likely to occur in some social environments than in others)? The traditional popular culture of Italy, as outlined by the preliminary results of a survey of collective rituals connected with earthquakes, appears to have been much keener on remembering past disasters than on removing their memory: so keen, in fact, that it still does preserve the memory of earthquakes that no seismic catalogue has recorded so far. The educational value and potential uses of this patrimony of shared memories are very interesting indeed.

### DEVELOPMENT OF A DISASTER RESPONSE EXERCISE SYSTEM – ID 1488

*Y. Hada, NIED, Japan*
*Y. Kawata, DRI, Japan*
*K. Sakamoto, Institute of Disaster Policy & Information Soc, Japan*

Enhancing the capability of practical disaster response for staff of disaster reduction divisions in local government has become a significant issue. As the solution for it, disaster response exercises (role-playing exercises) have begun to attract notice. However several demerits of the method are reported as follows. It is difficult “to manage information among players and controllers”, “to keep logs of exercises”, and “to analyze result of exercises”. In addition, it needs much time to prepare exercises. We therefore have developed of a disaster response exercise system for improving above points. Unlike most or the available techniques that based on the analogue way using situation/inquiry application cards, facsimile or telephones, the system is based on the internet technology. This paper introduces features and functions of the system and our developed scenarios for installing in the system. The system is composed of a server computer for a manager of exercises and client computers for controllers and players. The system is an interactive technique based on the Microsoft internet technology (Active Sever Page). Only Internet Explore application is required in each client computer to access the internet and/or intranet. Furthermore, the effectiveness is examined on training of the disaster response exercise system for local government personnel of disaster reduction divisions. From the results of the study, the developed system is expected to have efficient practical use and effectiveness for the assistant system of disaster response exercises.

### "LE VALAIS BOUGE !" (VALAIS MOVES !) A PUBLIC EXHIBITION ON EARTHQUAKES IN THE VALAIS ALPINE VALLEY – ID 1621

*J. D. Rouiller, CREALP, Switzerland*
*C. Lacave, Résonance Ingénieurs-Conseils SA, Switzerland*

Valais is the most earthquake prone region in Switzerland, and is furthermore characterised by strong 2D site effects. Owing to the exhibition "Le Valais bouge !" the whole population, and especially schools, will have the opportunity to get to know the destructive effects that a major earthquake could have on the Valais built environment. A special weight will be given to site effects in 2D alpine valleys and to basic principles making it possible to guarantee the seismic safety of buildings. This exhibition will first of all be educational. A visiting path will be created, presenting successively the source of earthquakes, their effects and measures that can be taken to reduce their effects. Taking place during the 47th Valais annual fair (150'000 visitors), in October 2006, this exhibition will certainly be the main attraction, thanks to the presence of a large public shaking table, for the first time in Switzerland. This earthquake "simulator", with a surface of 12 m2, allows ten persons to experience, in a very realistic way, a magnitude 6 earthquake in a classroom. People will be able to learn and practice the right behaviour to adopt in case of an earthquake. Public conferences will also be given, presenting the results of the Interreg III-B European project called Sismovalp (Seismic hazard and alpine valley response analysis), with a special accent on the Valais region. Every school in Valais will receive a documentation, inviting the teachers to program a visit to the exhibition next October. Teachers and children, and also the rest of the population, will so have the opportunity to learn about earthquakes and the way to react in case of such an event.

### EARTHQUAKES AND SCHOOL COMMUNITY - THEMATIC NETWORK EGELADOS – ID 1916

*G. Fermeli, Pedagogical Institute, Greece*
*S. Alexandropoulou, Environmental Education in Messinia Prefecture, Greece*
*E. Sokos, Lab of Seismology, Greece*
*P. Foundas, Industrial Systems Institute, Greece*
*N. Germenis, Lab of Seismology, Greece*

The thematic network "Egelados", deals with earthquake risk reduction through education activities at secondary school level. It is a collaboration between University of Patras (Seismological Laboratory, Industrial Systems Institute) and Directorate of Secondary Education of Messinia Prefecture (Office of Environmental Education). A team of teachers, researchers and engineers are involved, trying to fill the gap of earthquake preparedness, in high schools. Ten schools are participating in the network, located at Western Greece (Messinia - Peloponnese), the region with the highest seismic hazard in Europe. A specific curriculum has been drawn and is carried out through 20 educational activities, an independent project for each school of the network, as well as by the recording of the seismic activity through the “educational seismographs", which have been installed in the schools and were designed and assembled, specifically for the needs of the network. The specific aims of the network are: • to inform and raise the awareness of the students • to teach them how to react • to excite the interest of the local community • to transfer the specific knowledge from schools to families • finally, through the above, to raise the level of earthquake awareness of the communities

The network can run at two levels, both, national and international, in the first the students through the special educational activities, act as "real" seismologists recording, processing data and informing the school community and the local society about the results of their research. In an international level, the network aspires to cooperate with schools, institutes and other networks from all over the world, by exchanging methods and experience.Through this network, we hope that students will understand that seismic activity is natural phenomenon for their region and they will learn how to protect their life and the community, from this.

### LET'S GO VISIT CITTA' DI CASTELLO IN 1789 – ID 1969

*V. Castelli, INGV, Italy*
*R. Camassi, INGV, Italy*
*E. Ercolani, INGV, Italy*
*L. Postpischl, INGV, Italy*

On September 30, 1789 a strong earthquake took place in the upper reachs of the Tiber plain, between Città di Castello (Umbria) and Sansepolcro (Tuscany). Several of the villages scattered through the plain and the nearby hills suffered very high damage, with many casualties (60 only in the hamlet of Selci). Città di Castello and Sansepolcro - whose buildings had already been shaken by the Cagli earthquake of 3 June 1781 - were also greatly damaged. A wealth of contemporary documents describing the effects of the 1789 earthquake is available, including, for Città di Castello itself, a house-to-house damage survey. By georeferencing the survey data on a contemporary map it has been possible to match many of the buildings mentioned in the survey with their actual counterparts in present-day Città di Castello. This paper proposes a virtual exploration of Città di Castello as it was at the time of the 1789 earthquake: an interactive journey through time and space expressly designed for secondary school students allows to explore several thematic levels to discover the town as it was in 1789, the historical evidence of the earthquake effects on the local buildings and people, in order to gain knowledge of what could happen today should an earthquake of the same kind occur in Città di Castello.

### EARTHQUAKE SCENARIOS FOR EDUCATIONAL SHAKE TABLE – ID 2022

*V. Kouskouna, University of Athens, Greece*
*D. Diagourtas, University of Athens, Greece*
*N. Galanos, University of Athens, Greece*
*K. Makropoulos, University of Athens, Greece*

Within the educational centre SEISMOPOLIS (Athens, Greece) one area is dedicated to the earthquake simulation, where an educational shake table (6mX3m) has been installed. The area has been transformed into a kitchen, where the visitor can

experience the earthquake and its effects. Taking into account the seismicity of Greece, three most probable scenarios of earthquake shaking were chosen, suitably modified so as not to create negative reactions from people acutely sensitive to this phenomenon and to guarantee the safety of the visitors. The above scenarios can be generally described as follows: - a large, widely felt distant event: Kythira, 8Jan2006 - a large local event: Parnitha (Athens) 7Sep1999 and - a minor felt event: aftershock of the Parnitha earthquake During the tests carried out in the beginning of the pilot phase, the three input accelerograms corresponding to the above three events were also recorded by an accelerograph. The records provided information concerning the necessary filtering that should be applied in order to produce the level of input acceleration and frequency content that rationally represent the desired degree of shaking.

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