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Title of the Session: Seismic Risk Assessment of a City

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Summary

Earthquake hazard is a natural phenomenon such as ground shaking or liquefaction that is generated due to an earthquake, which may occur at any time without warning and has the potential to inflict huge socio-economic losses. The socio-economic losses in an earthquake are related to loss of life and property (buildings and infrastructure also referred as exposure). Vulnerability refers to degree of fragility of the buildings and infrastructural elements to earthquake ground motion. Earthquake risk, on the other hand, is the probability that it will cause damage to life and property, if they are exposed to earthquake hazard.

The terms, earthquake hazard, exposure, vulnerability and earthquake risk, though fundamentally different concepts, are related to each other. Earthquake hazard is a natural phenomenon and it may or may not be possible to reduce or mitigate it. However, exposure and vulnerability are man-made and could be reduced or mitigated. Thus, earthquake risk could be reduced or mitigated by reducing the exposure and or vulnerability. The note briefly explains these concepts and steps required for earthquake risk assessment of a city or an area through an earthquake modeling framework.

Context

Earthquake hazard is a natural phenomenon such as ground shaking or liquefaction that is generated by an earthquake, which may occur at any time without warning and has the *potential* to inflict huge socio-economic losses. The socio-economic losses in an earthquake are related to loss of life and property (buildings and infrastructure also referred as *exposure*). Vulnerability refers to degree of fragility of the buildings and infrastructural elements to earthquake ground motion. Earthquake risk, on the other hand, is the *probability* that it will cause damage to life and property, if they are exposed to earthquake hazard. Thus, earthquake risk is a function of earthquake hazard, exposure and vulnerability:

Earthquake Risk = f (Hazard, Exposure, Vulnerability)

Since, earthquake hazard is a natural phenomenon; it may or may not be possible to reduce or mitigate it. However, exposure and vulnerability are man-made and could be reduced or mitigated. Thus, earthquake risk could be reduced or mitigated by reducing the exposure and or vulnerability.

Earthquake hazard is assessed from the history of past seismicity (historical and instrumental earthquake catalogs); seismotectonics-geological fault’s (source) parameters; ground motion observations and path characteristics (attenuation relations) and soil characteristics. Thus, earthquake hazard is quantified spatio-temporally by the level of ground motion parameter (earthquake magnitude with a reoccurrence interval, Peak Ground Acceleration (PGA), Spectral Acceleration (Sa), Spectral Velocity (Sv) or Spectral Displacement (Sd). Occurrence of magnitude 6.5 earthquake on Main Central Thrust (MCT) in Himalayas with a mean re-occurrence interval of 10 years and a PGA level of 0.28g with a return period of 50 years at a city centre, say Mussoorie in Himalayas are examples of earthquake hazard.

Earthquake risk assessment is a challenging task because it not only depends upon the earthquake hazard but also on the spacio-temporal interaction of hazard, exposure and vulnerability. Thus, earthquake risk can be quantified in terms of probabilities that N number of buildings could be damaged slightly or moderately; or Average Annual Loss of X amount; or loss of Y amount and N number of human casualty for a ground motion corresponding to, say, 475 year return–period. The earthquake risk can be assessed site-specific (for a specific building/structure), or over an area specific. The spacio-temporal interaction of hazard, exposure and vulnerability could be modeled through a time-predictable, Brownian Passage Time (BPT), or the Poisson process for earthquake occurrence in time. The most commonly used earthquake occurrence model is the Poisson process. Thus, for earthquake risk assessment, a modeling framework is generally introduced as shown in Figure-1.

Figure 1: Earthquake Modeling Framework

(a) Hazard Module

The principles of Probabilistic Seismic Hazard Analysis (PSHA) started in 1968 by Cornell (Cornell, 1968). Subsequently several researchers refined the methodology time to time (WGCEP, 2003; Frankel et al, 2002 and many other).

The basic steps involved in seismic hazard assessment are (Figure 2):

❖ ***Define source zones:***

A number of source/fault zones for the study area and the surrounding region are demarcated. For each fault or source zone, the sense of motion (fault type), a characteristic magnitude and activity rate (for individual fault) or a maximum magnitude and observed earthquake frequency-magnitude relationship (for source zones defined by seismicity) is estimated. Data from historical earthquakes of study and surrounding area help guide the shape of the tail of the intensity distribution. In order to capture the uncertainty in long-term earthquake behavior, the assumption is made to consider the possibility that contiguous sources might sometimes rupture together, creating a much larger earthquake.

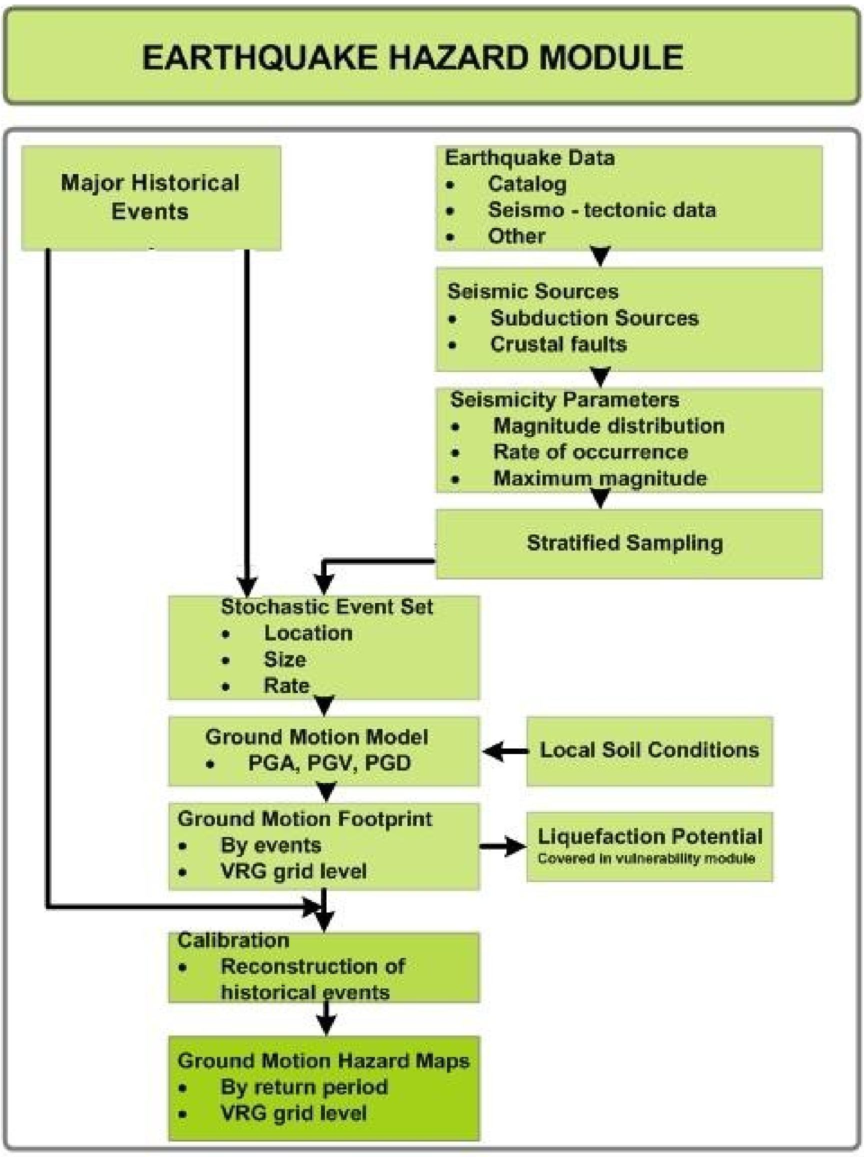

Figure 2: Earthquake Hazard Module

❖ ***Create a Stochastic Event Set***

Stochastic event set consisting of hundreds of potential earthquake events are created using computer simulation techniques. Stochastic earthquake event set is generated for each seismic source zone by randomizing the input parameters of seismicity (location of fault, magnitude and depth) within well-established geophysical bounds.

❖ ***Compute Hazard Footprints***

Hazard footprints, the areal distribution and intensity of shaking for each event in the stochastic event set are computed. This module also models the attenuation of ground motion with distance from the earthquake and incorporates effects of local site conditions that may amplify or reduce the shaking levels.

Three different parameters that govern the damageability associated with earthquake ground motion are:

- Measures of peak ground motion- Peak Ground Acceleration(PGA), Peak Ground Velocity (PGV), or Peak Ground Displacement (PGD)
- Frequency content of the seismic energy
- Duration of shaking

In practice, all these parameters are not known precisely in areas where there have been relatively few recordings of strong damaging seismic shaking. When instrumental recordings (acceleration time histories) are rare for a region, PGA is generally chosen as a simple but robust measure of ground motion and damage, at a minimum, to characterize the ground motion. If enough seismic strong motion recordings are found to exist for the study region, spectral accelerations are used as a descriptor of earthquake ground motion. To capture uncertainty, generally, use of more than one attenuation relationship is made and weighs them within a logic tree approach.

Local site response due to variation in near-surface geology significantly impacts the earthquake ground motion, resulting in structural damage. The Vs^{30} measurements (average shear-velocity down to 30 m depth) are commonly used to define categories of site response. In absence of detailed geological and lithological data, use of topographic slope as a proxy is made (Wald and Allen, 2007) to determine local seismic site conditions. Wald and Allen (2007) correlated variations in local topographic slope with observed Vs^{30} measurements and with soil conditions inferred from soil mapping to develop coefficients that vary by region.

❖ ***Calibration with historical data***

The spatial pattern of shaking intensity from the ground motion footprints for well known historic earthquakes in study region and surrounding regions having similar seismotectonics conditions are cross checked against the direct ground motion measurements from strong motion recordings of recent earthquake and historic accounts and damage reports of past earthquakes. The following information is generally derived in each cell:

- Soil characteristics
- Ground motion estimates taking into account local soil conditions and expressed as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD) at the centroid of the cell.

(b) Exposure Module

The exposure development process basically involves the tasks of classification and quantification of the exposures at grid, locality, ward, and city levels. The assets are required to be sorted in classes/sub-classes that exhibit similar behavior under ground shaking excitation to facilitate the estimation of damage. Vulnerability/damage functions are developed for exposure sub-classes. In addition of classification of assets, an estimate of the replacement value of the assets (structure and their content value) is also made to quantify the damage in terms of economic losses.

Classification of exposure
For buildings

- Occupancy
- Building material
- Roof Type (Flat, Slope)
- Design philosophy (Shear walls, moment-resisting frame)
- Age group
- Importance of the structure

In such analysis, an inventory of all the three major classes of buildings- residential, commercial and industrial is developed.

Quantification of Exposures

The exposure replacement cost for all exposure classes and sub-classes are derived at locality/ward levels using data available from secondary sources such as public works department, construction companies.

(c) Vulnerability Module

This section focuses on assessment of physical vulnerability of buildings to ground shaking. Physical vulnerability refers to the *degree to which an asset would get damaged or destroyed in a hazardous environment caused by a damaging earthquake*. The vulnerability module quantifies the damage susceptibility of each asset class with respect to varying levels of ground motion. Damage susceptibility associated with a given level of hazard is measured in terms of a *mean damage ratio* (MDR) defined as the ratio of repair cost to replacement cost of the asset. The curve that relates the MDR to the hazard is called a *vulnerability function*. Vulnerability functions are developed for buildings and structures using analytical and statistical methods complemented with expert or heuristic judgment.

The following general classes of physical and human assets are likely to be affected directly by ground shaking hazard and associated collateral hazards:

General Buildings

* Residential buildings
* Commercial buildings
* Industrial buildings and structures

Essential Facilities

* Educational buildings
* Medical buildings
* Fire stations
* Police stations
* Public buildings
* High occupancy buildings (such as shopping complexes)

Shelter facilities

These represent the buildings that have been identified as possible shelter locations, in case of a damaging earthquake. Information that is usually captured for shelter facility is:

- Location
- Type
- Capacity (number of people)

Development of Vulnerability Functions

Development of vulnerability functions for buildings, lifelines and other facilities are generally based on damage data from local historical events, however, most often such data are not sufficient because of the scarcity of such information. Therefore, a statistical approach complemented by engineering analyses along with expert judgment based is generally adopted (Arya, 2003a&b). Usually, development of the vulnerability functions relies on three different components i.e., damage statistics of the past events both local and global, analytical/engineering studies and the results of solicitation of expert opinion.

(d) Damage/Loss Module

The direct physical damage to buildings is computed by integrating the hazard, with the exposure and the vulnerability.

The damage levels are expressed in three ways: mean damage ratio (MDR), probability of being in a specific damage state or level of functionality. Depending upon the type of asset, the most applicable damage level is selected for quantifying the damage. Damages can be assessed at the grid level and aggregated to ward/city level.

(e) Social Module

Social vulnerability is the quantification of susceptibility of populations to death and injuries as a result of an earthquake event. This assessment involves casualty modeling to compute mortality and injury rates associated with various size events. The outdoor populations are treated separately since they are not generally vulnerable during an earthquake (Spence et al, 1991, 1992; Singhal, and Kiremidjian, 1997; Jose et al, 2005).

Casualty

The Casualties are estimated by combining the output from the building damage with building inventory and population data to quantify casualties. The output of the casualty module contains estimates of four casualty severities by general occupancy and time of the day. The casualty severities range from "*Severity 1: First aid level injuries not requiring hospitalization*" *to* "*Severity 4: Instantaneous death or mortal injury.*" Casualty rates, which vary according to type of construction, are based on recent earthquakes with inventories similar to the study area. In general, casualties estimate are carried out for three times of the day: 2:00 P.M. (during office hours), 5:00 PM (commuting time) and 2:00 A.M. (at night) based on derived migration patterns of the region's population.

Subsistence Requirements

Subsistence requirements arising as a result of an earthquake are derived by combining the damage to residential building stock with utility service outage relationships to estimate the number of households that are uninhabitable. The uninhabitable household estimates are combined with demographic data to quantify the number and composition of the population requiring both short-term and long-term shelters. The output of the shelter module is expressed as estimates of the number of displaced households and short-term and long term shelter requirements. The estimates are based on statistics from recent event in areas with similar infrastructures and demographic patterns.

The shelter facilities that could be used for temporarily housing people is dependent upon whether it is damaged or not and has electric power and potable water supply. The additional shelter facilities needed to accommodate all the people looking for temporary shelter are a function of the capacity of undamaged pre-identified shelter buildings.

The earthquake risk assessment models are highly region-specific and their accuracy in predicting damage/loss in a future event depend on the quality of region-specific data on historical earthquake catalogs, seismotectonics, ground motion source and path characteristics, earthquake occurrence model, soil characteristics, exposure characteristics, and the resolution of the model. The damage computation model could be built at a resolution of grid level. The intended grid resolution for the model could be Variable Resolution grid (VRG) or Uniform Grid Level (URG). Hi-resolution uniform or variable grids designed based on the population density and hazard severity are overlaid on the modeled regions to capture all input data and information at grid level. Further, the models need to be calibrated and validated against loss/damage data available for recent historical events that have affected the region or regions with similar inventories. While probabilistic models are used in the insurance industry deterministic or scenarios based models are more suitable for disaster management planning.

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