National Survey for Seismic Protection of the Republic of Armenia

REPORT

on

SEISMIC RISK ASSESSMENT AND ITS REDUCTION ON THE TERRITORY OF THE YEREVAN CITY

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Table of Contents

page

1. Introduction

As determined by both objective and subjective factors, the seismic risk of Armenia has, at the present time, reached its highest level over the entire historical period (Balassanian, Manukian, 1995 [1]). As A. Hajian, the known expert, said - Armenia is the "national at risk".

Practically all of the territory of Armenia is situated in a seismically-active zone. The size of earthquakes ranges up to $M=7.1$ (according to instrumental recordings) and $M=7.5$ (according to historical and paleoseismic estimations). Focal depth is, on average, 10 km. All sources are located on the active faults, with an average slip rate of about 1 cm/year. The duration of destructive earthquakes may reach one minute under adverse ground conditions. The average recurrence interval of large earthquakes ($M\geq5.5$) comprises 30-40 years.

A large earthquake is particularly hazardous in the region of Yerevan, the capital of Armenia, because of the following factors (Balassanian, 1995 [2]):

- High population density - 106 people per square km under extremely uneven distribution of the population - more than 40 per cent of the republican population reside in the city of Yerevan;
- Seismically non-resistant housing, structures, communications;
- High concentration of hazardous facilities: nuclear power plant, chemical plants, dams, etc., all having a low level of earthquake resistance;
- Toxic-material and hazardous plants are located within the limits or in the vicinity of densely-populated areas;
- Cites and large communities built on poor grounds as, for example, Giumri (Leninakan), the second largest city in Armenia;
- Sharp deficiency in instrumental observations, prohibiting a reliable assessment of the long-term and current seismic hazard;
- Insufficient preparedness of the Government for undertaking decisive actions immediately before, during and after an earthquake;
- People untrained in the rules of behavior before, during and after an earthquake;
- Absence of appropriate material and technical resources in the republic for prompt evacuation, relief and recovery, and;
- Hard economic problems caused by the period of transition to another social order.

2. Demography of the city of Yerevan

1.26 million people reside in the 210 km^2 territory of the city of Yerevan. A high rate of population growth is one of the distinctive features of the city. From 1917 to 1988, the population of Yerevan increased by a factor of 30, with a consequent increase in seismic risk, as determined by the following factors:

- The rapid and cheap construction of houses and city lifelines (including communication, electric power supply, and water supply) in response to population demands, led to an inadequate quality of construction.
- Districts of multi-story buildings appeared whose design level of earthquake resistance corresponded to a VII-VIII intensity on the XII-intensity MSK scale; whereas the level of possible seismic hazard was greater than or equal to IX intensity.
- Within the city limits, the construction of toxic-material and hazardous facilities was begun. Since these plants required a large construction area, a deficiency of space in the center of the city resulted, and the

construction of underground structures designed with regard to VIII-intensity seismic hazard was needed. This was considered to solve not only the problem of useful space but also the problem of separating the vehicle and pedestrian, traffic over two different surfaces (levels).

The population density is distributed extremely unevenly over the city and has, as a result, created an imbalance in the operation of communication systems, with parts of them not used in full measure and other parts severely overloaded. Moreover, within the city limits, population growth forced areas of many differing altitudes to be inhabited. This severely hampered the development of effective lifeline systems and limited their capacity.

Various migration processes formed the base of Yerevan's population, creating a distinctive way of life for the whole city. According to their places of origin, emigrants could be divided into four categories: rural emigrants, town-dwellers from Armenia, town-dwellers from other republics of the former USSR, and repatriates. In addition, from 1988, the city began receiving refugees (whose numbers totalled 100,000 people) and residents of Northern Armenia who were displaced by the Spitak earthquake.

The catastrophic Spitak earthquake of 1988 occured at a distance of 100 km from Yerevan and resulted in the death of 25,000 people. Moreover, 20,000 people were injured severely and 515,000 people were made homeless (Balassanian, et. al, 1995 [3]). This disaster gave rise to a difficult economical situation in the Republic, followed by unemployment; the period of transition from one social order to another was felt keenly. The people experienced deep psychological stress, a sharp drop in living standards, noticable emigration from the Republic, and a total change of the way of living and psychology.

The abovementioned conditions were accompanied by a depletion of Yerevan's material resources and an aggravation of municipal services, condition of lifelines and housing; therefore the seismic risk in Yerevan has reached a very high level.

3. Characteristics of the seismic hazard zone for Yerevan

We have defined the seismic hazard zone of Yerevan based upon the location of active faults and sources of potentially hazardous historical earthquakes.

The part of Yerevan defined by latitudes of 30.5 and 40.5 degrees north and longitudes of 43.5 and 45.3 degrees east has been exposed to destructive earthquakes in the past. Previously, this territory was selected and special seismological investigations were carried out by Karapetian (1986) [4].

3.1. GEOGRAPHIC POSITION

Yerevan's seismic hazard zone is situated in the Ararat valley and outlined by the southern spurs of the Tsakhkunian range: Aragats (4000 m high) and Arailer (2500 m high) mountains to the north; Greater Ararat (5,165 m high) and Lesser Ararat (3,925 m high) mountains to the south; Arghidag range on the southwest; and Ghegam range and Sevan lake on the east.

The average altitude of Yerevan is 1,100 m. The city relief is sharp, with elevation changes reaching 400 m within the city limits.

3.2. GEOLOGICAL AND ENGINEERING GEOLOGICAL CHARACTERISTICS

The Yerevan seismic hazard zone consists of 4-5 km of volcanogenic sedimentary rock underlain by a metamorphosed paleozoic crystalline basement. Volcanogenic sedimentary rock mass is represented therein from bottom to top as follows: chalky porphyrites, sandstones, clays, limestones in alternation; paleogene sand, tuff, clays, andesites; neogene alternation of gypsum and clays, andesite-basalts, andesites; Quaternary tuffs, basalts and alluvial-diluvial deposits. Metamorphosed rocks of the crystalline basement involve methamorphic schists, quartzites.

The Yerevan city territory, in its different parts, is composed by rocky and large-debris grounds, rocky weathered grounds, coarse-grained sands, clays, sandrocks, and clayey ground.

Ground water level in the region of Yerevan city is on average at 7-8 meters depth.

3.3. SEISMICITY

The chronicle of large earthquakes resulting in human fatalities and the destruction of cities and villages in the territory of Yerevan's seismic hazard zone starts in 550 B.C. The entire historical period from 550 B.C. to 1993 is naturally divided into two parts: historical (550 B.C. - 1932) and instrumental (1932-1993). Altogether, 223 earthquakes of different intensity have been revealed and recorded according to macroseismic (till 1932) and instrumental (since 1932) data within the time interval 550 B.C. to 1993. Derived from those data, the statistics of large earthquakes are as follows.

According to the macroseismic data, one large earthquake of $M=7.4$ and one of $M=7.0$, five earthquakes of $6<M<7$ and ten of $5<M<6$ were revealed for the period from 550 B.C. to 1932.

For the instrumental period (1932-1993), one earthquake of $M=6.2$ and four events of $5<M<6$ were recorded. By the "large earthquake", an earthquake of $M=7$ is generally meant, but because of Yerevan's seismic risk, we use the term "large earthquake" for those of $M=5$ or greater, since the occurance of such an event in Yerevan (or any other populated area of Armenia) could cause significant damage, given the dilapidated state of buildings-particularly those in the private sector-and poor-quality construction in the state sector.

When trying to reveal a certain regularity for the occurrence of large seismic events in time within the limits of the considered zone, it is necessary to take into account noticable heterogenity of the data in the earthquakes' temporal row, for the period from 550 B.C. to 1993.

The overall temporal domain can be divided into three quasi-homogeneous ranges in accordance with the quality of data: I (550 B.C.-1932) - historical, pre-instrumental period; II (1932 - 1962) - instrumental period when the limited number of stations in the Caucasian regional network was operating; III (1962-1993) - instrumental period when the Caucausian regional seismic observations network operated, including implementation of the Armenian national telemetring seismographic observation network (NSSP network).

Within the I range, seismic activity periods for the events of $M=5.5$ covering approximately 300 years and passivity periods of the same duration stand out since 736. When this regularity is projected to the future, the next large earthquake of $M=5.5$ may occur in 2140, i.e. 300 years after the largest Ararat earthquake of 1890 ($M=7.4$). Within the II and III range periods (instrumental), which may be combined when considering large earthquake statistics, approximately 15-year-long cycles of earthquake ($M=5.0$) recurrence stand out. When this regularity is projected for the future, the next large earthquake with $5<M<5.5$ would be expected by 2007, as far as the last large earthquake of $M=5$ occurred in 1992 (Martini earthquake on the territory of Armenia). It should be noted that the 1986 Martuni earthquake was conceptually predicted by Karapetian (1986), who had forecast the 1992 earthquake of $M=5.2$ in this region on the basis of large earthquake energy emission statistics for the investigated territory. Finally, it should be noted that the recurrence cycles of large earthquakes in the zone of seismic hazard for Yerevan have a very approximate nature. It will be possible to make more precise conclusions after careful study of new data on historical seismicity, re-estimation of old results using new procedures for large earthquake parameters macroseismic assessment, and metrological assessment of the accuracy of all instrumental data are performed. Besides, the recurrence cycles of different intensity earthquakes within small zones, in our opinion, depend on the general regional dynamics of seismic processes. The character of these dynamics is that, along with a certain periodic component, a random component is practically always observed. Reasoning precisely from the above-mentioned factors, the NSSP of Armenia considers current seismic hazard assessment very important. The seismicity of the territory (for the period of 1985-1993) outlined by four main active faults of Armenia is given in Figure 1. From these data it is clear that since 1992, the temporal process of seismic events resembles the period preceding the catastrophic

Spitak earthquake.

3.4. ACTIVE FAULTS, SEISMOTECTONICS AND HISTORICAL SEISMICITY

Several large faults of different orientations, each having large earthquake sources, are distinguished by different authors on the territory of seismic hazard for Yerevan. In particular, Karakhanian distinguishes the Garni fault, the Arax active fault and the Yerevan hypogene fault, which does not manifest noticable current activity but retains the potential hazard of activation [Figure 2].

In addition, Yerevan is exposed to severe hazard from large earthquake sources which destroyed the city structures or caused significant damage to them in the past. Among the farthest from Yerevan is the source of the Ararat earthquake that occurred on 2 June 1840, with M=7.4; the Ararat event was the largest earthquake in the region of Yerevan and also one of the largest in the Armenian Upland. The destructive effect of this earthquake was felt throughout the greater Yerevan area, despite the fact that the epicenter lay 90 km southwards from the city.

In the hazardous vicinity of Yerevan, 20 km southeast from the city, is situated the source of the large Dvin earthquakes. This source manifested especially high activity from 851 to 893. During this rather short interval, five of the large seismic events occured in 851, 858, 863, 869, 893, among them the largest of M=6.0 in Spring, 893. Victims of this earthquake numbered 70,000, and the city was totally ruined.

The Arax active fault, located 20 km southwards from Yerevan, presents significant hazard to the city. This is a dextral strike-slip fault where, according to Karapetian (1986), epicenters of the Igdir group earthquakes (the largest of which took place in 1963 with M5.2) are associated. Large earthquakes along this fault occured in 139 (Ararat mountain, M5.7) and 1841 (Kavdak, M5.7).

The Yerevan hypogene fault revealed by Aslanian (1981) [5] presents an immediate hazard to the city. The Parakar source of large earthquakes associated with it is known for the earthquake sequence known as the Yerevan earthquakes: 1910 (M4.5), 1937 (M4), 1973 (M4), and 1984 (M4). The largest among them was the 1937 earthquake, during which some buildings in Yerevan were damaged due to their dilapidated state, unfavourable ground conditions, and the low quality of construction.

According to the data of Karapetian, if the last three Yerevan earthquakes are related to the third seismically-active period (of the Parakar source) assuming 1973 as its start, then the average recurrence interval for large earthquakes (M4.5-5) epicentered in the Yerevan city region in the 20th century will be 27-36 years.

We consider that the Garni active fault distinguished by Trifonov and Karakhanian is more hazardous that the direct threat of the Yerevan hypogene fault (Trifonov et al.,[6]). The Garni fault passes 10 km northwest of Yerevan. According to Trifonov et al., this is a right slip with reverse fault component extending in a northwest direction on the territory of Armenia. The length of the faults is 166 km. Amplitude of horizontal displacements for Holocene ranges up to 50-100 m and 200 m for the late Pleistocene. Average horizontal displacement velocity is 3-5 mm/year. This fault is associated with epicenters of large earthquakes.

It has been the activation of the Garni fault which, in Trifonov's and Karakhanian's opinion, primarily led to the catastrophic Spitak earthquake (7 December 1988, M7.1) - the largest seismic event in the territory of Armenia in the entire instrumental observation period.

Among the large earthquakes associated with the Garni fault, that which occurred on 4 June 1679 should be distinguished. It destroyed the city of Yerevan and numerous villages in the Ararat valley. More than 8000 people died in Yerevan, and the whole of population of neighbouring Kanaker village was wiped out (1,228 people). In Garni settlement, 7,600 people died. Aftershocks of the earthquake continued through the end of

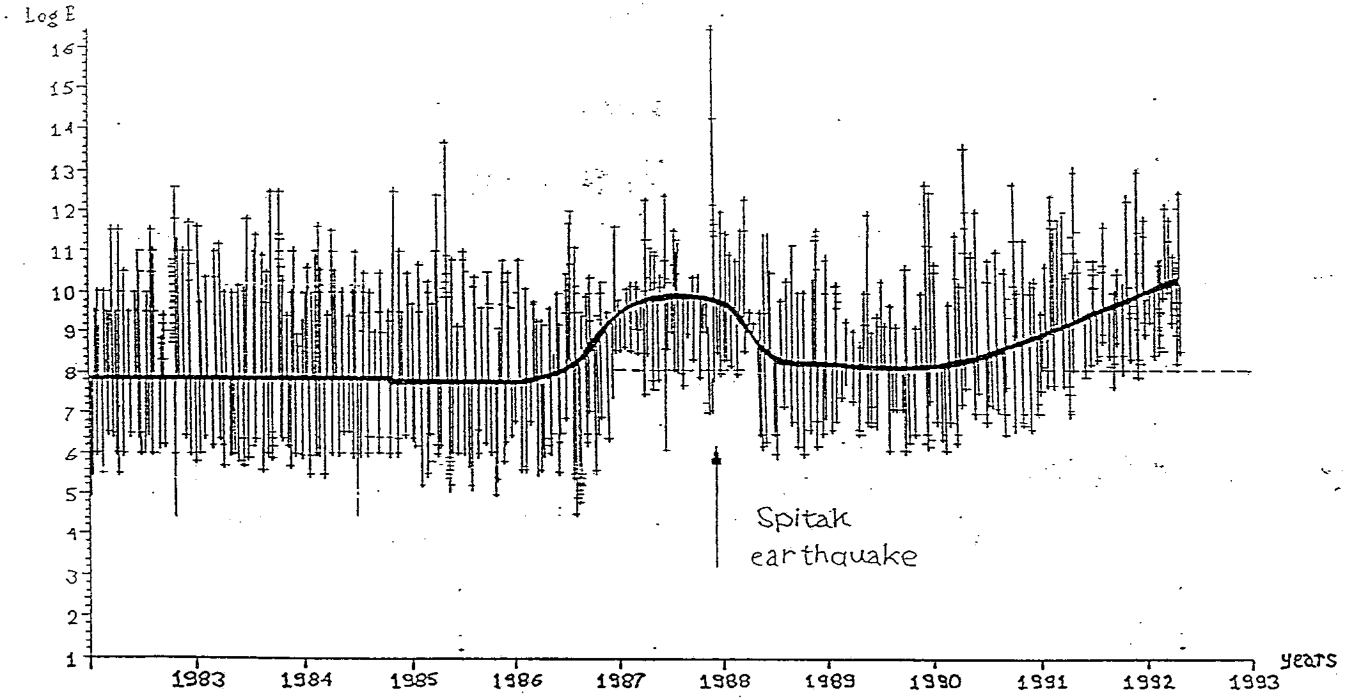

Figure 1. Seismicity of the territory outlined by four main active faults of Armenia
(for the 1983 - 1993 period)

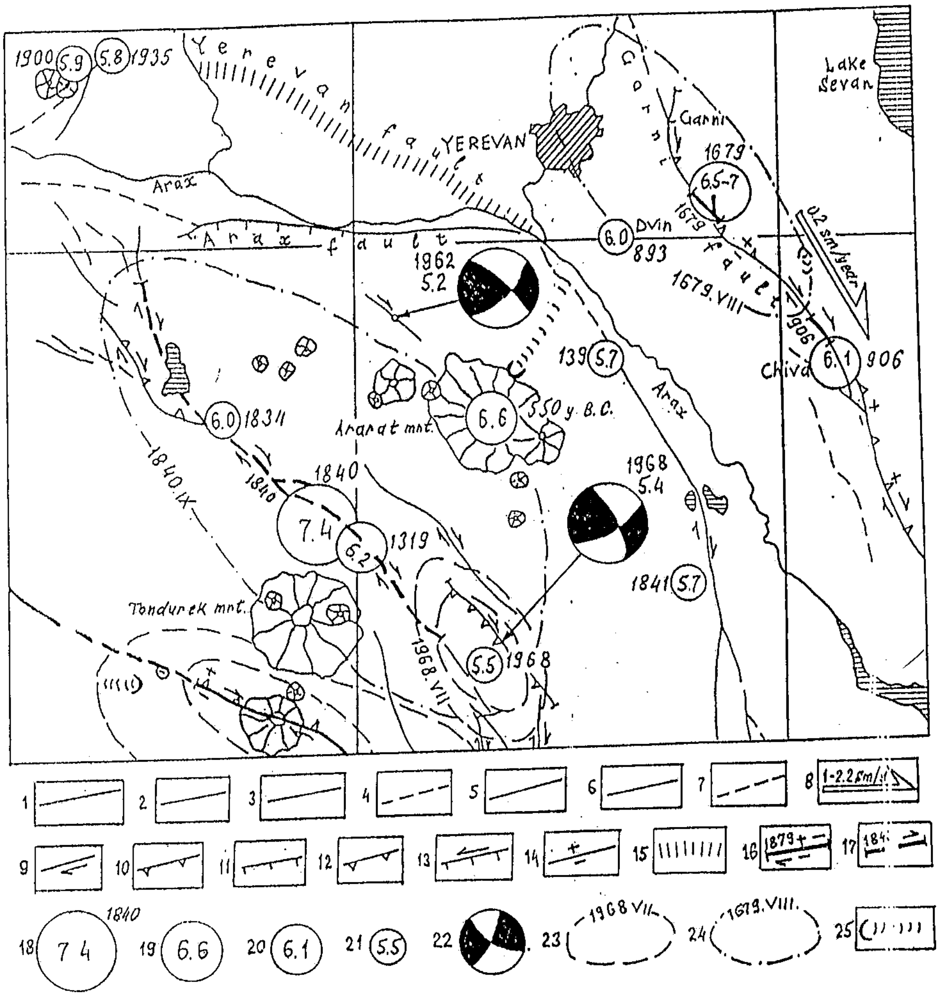

Figure 2. Fragment of the map of active faults and seismotectonics of Armenia (composed by A. Karakhanian, R. Aroutiunian) - seismic hazard zone for Yerevan city

1 - the faults active in Holocene (and late Pleistocene); 2 -the faults active in Pleistocene (the last 0.7 million years and only supposed to be active in Hollocene); 3 - proved; 4 - supposed on indirect signs (results of air-space photoes decoding, seismic and fluid gas activity); 5 - transregional (> 0.5 cm/year); 6 - regional (0.5 - 0.1 cm/year); 7 - local (the others); 8 - direction of horizontal displacement along the faults and average intensity; 9 - strike slip faults; 10 - reverse faults and thrusts; 11 - normal faults; 12 - strike slip and reverse faults; 13 - strike slip and normal faults; 14 - vertical displacements; 15 - concealed faults of the basement; 16 - documentally confirmed seismogenic ruptures (seismotectonic dislocations); 17 - seismogenic ruptures supposed on the historical data and fragment field investigation results; 18 - earthquakes (year and magnitude are indicated) of M>7.1; 19 - earthquakes of 6.6<M<7.0; 20 - earthquakes of 6.1<M<6.5; 21 - earthquakes of 5.5<M<6.0; 22 - focal mechanisms of earthquakes; 23 - the highest marked isoseisms on the contemporary data; 24 - the highest marked isoseisms on the historical data and contemporary field studies of historical structures; 25 - Holocene seismogenic landslides.

the year. According to the available historical data, the 1679 Garni earthquake was the most destructive in the history of Yerevan, which was founded in 782 B.C. (Erebouni).

The extreme hazard of the Garni active fault for Yerevan is substantiated by the following: (1) Spatio-temporal migration of large earthquake sources from the southeast towards the northwest; 906 (Vaiotsdzor, M6.1); 1679 (Garni M6.5-7); 1827 (Tsakhcadzor, M6.7); 1988 (Spitak, M7.1) and (2) by the descending time interval between large seismic events.

In A.Karakhanian's opinion, who had noticed this regularity, it is quite possible that the large Garni earthquake sequence will repeat again, starting from the Vaiotsdzor source (Balassanian et al, 1993 [7]). Activation of the Vaiotsdzor source started in 1992 with a swarm of earthquakes (M2-3), anomalous changes in ground water level, intensive changes of soil gas radon concentration, and other relevant signs.

4. Earthquake resistance of buildings and structures in Yerevan

It is common knowledge that seismic risk depends on the earthquake resistance of buildings and structures within the populated area, more than any other factor. Earthquake resistance of buildings is determined by the buildings design, quality of building materials, construction quality, and building maintenance.

The most general design concepts in Yerevan are the following: (1) Low-rise stone masonry (private buildings); (2) Stone and complex buildings up to 5 story; (3) Large-panel prefabricated buildings up to 9 story; (4) Frame-and-panel buildings up to 9 story; (5) Buildings constructed by lift slab method up to 16 story; (6) Frame and braced-frame buildings up to 16 story.

The most general soil types upon which buildings are constructed are: (1) rock and large-debris; (2) weathered rock; and (3) sandrocks.

Eighty percent of the buildings are designed by specialized institutions. A city planning division of 32 employees works within the municipal staff under the Mayor.

Yerevan is being developed in accordance with a masterplan of city development. Before 1960, construction of Yerevan had mainly been done without proper consideration of the territory of Armenia's seismicity. Since 1960, a construction code accounting for the seismicity of Armenian territory began to be used. These code were in effect until 1969, when a more developed code was established and enforced until 1981.

In 1981, the new code was approved, according to which, when designing buildings and structures for construction in seismic region, the following requirements had to be met: (1) to use materials and design concepts providing adequate values of seismic loading; (2) to approve, as a rule, symmetric design schemes, uniform distribution of construction rigidities and masses (from construction units and loadings upon the slabs); (3) to locate joints out of the maximum stress in prefabricated type buildings, to provide monolithic character and homogenity by using integrated precast units; and (4) to allow for the conditions facilitating plastic deformations development within structural units and their joints, as well as providing general resistance of the structure.

When designing building and structures for the construction in seismic regions, it is necessary to take into account both the intensity of seismic impact measured in MSK intensity (seismicity) and the recurrence of seismic impact. For Armenia, the intensity and recurrence had been estimated on seismic zonation maps of the USSR territory. Seismicity estimation for the construction area was made based on the seismic microzonation map. Construction of buildings and structures on the areas with estimated seismicity exceeding IX in MSK scale was forbidden. However, in order to allow for the development of rapid and cheap construction, steps were taken to underestimate, artificially, the seismic hazard of Armenia.

As a result, a seismic zonation map indicating the Spitak earthquake source zone as one of the most undangerous in the territory of Armenia was composed by the Armenian SSR and the USSR Academies of Sciences, and it was approved by the USSR Gosstroi in 1976, In this map, the rate of hazard was underestimated by 3 to a 7 intensity, instead of 10 (on the 12-intensity MSK scale). Therefore, seismic hazard was not properly considered when designing buildings and structures.

After the 1988 Spitak catastrophe, seismic code were reviewed significantly in 1989. The main changes to the code were to increase the intensity-grading in the territory of Armenia.

In 1992, the National Survey of Seismic Protection (NSSP), under the Government of the Republic of Armenia started composing maps of seismic hazard and seismic risk in different scales, including in them the city of Yerevan (Balassanian and Manukian, 1994 [8]). At the present time, new seismic code is prepared where MSK scale intensities are changed by ground accelerations, and the requirements to the structure's design become more stringent. A revised seismic microzonation map is also being prepared.

5. Preparedness for earthquakes

Before the 1988 Spitak earthquake, neither the leadership of the Republic nor the population had been prepared to protect the Republic against a large earthquake in the territory of Armenia. For a number of reasons this problem has not been considered at all. These reasons included the following: (1)Protection of people against earthquakes was not considered an all-Union problem in the USSR, because only an insignificant part of the Soviet population resided in seismically-active zones; consequently, only the USSR Academy of Sciences was concerned with earthquakes, and they considered them merely as interesting natural phenomena; and (2) the solutions to all problems in the USSR were strongly centralized, and the leadership of the Republic was not able to put forward or solve any large-scale problems requiring great material expenditures and resources.

The period following the Spitak earthquake coincided with a period of social order change in Armenia and its formation as an independent state. This allowed us to advance the problem of protecting the Armenia population against large earthquakes to the foreground of national problems.

According to the project proposed by S.Balassanian to the President, Parliament and Government, the National Survey of Seismic Protection of Armenia (NSSP) was founded under the Government of the Republic of Armenia on 17 July 1991 and furnished with special governmental status and powers (Balassanian, 1995 [9]).

The main task of the NSSP is long-term, mid-term, and short-term, operative assessment of seismic hazard and risk in the territory of Armenia, and the development and implementation of long-term and operative measures for seismic risk reduction in the territory of Armenia.

In order to attain this goal, a special NSSP structure (Scheme 1) was developed that combined two necessary organizational principles of seismic protection under the conditions of Armenia: (1) joint operation of different centers, covering the entire spectrum of seismic protection tasks, and integrated by the common goal, structure and working programme; (2) vertical subordination of all divisions within the NSSP under its President, who is in turn submitted directly to the Prime Minister. Since the organization of the NSSP in Armenia the preparedness of the Government and the population for large earthquakes had been improved substantially. The NSSP leadership regulary reports to the Prime Minister about the level of seismic hazard in the Republic and the measures that should be undertaken to reduce the seismic risk.

At the present time, special regulations are being developed by the National Survey for NSSP interaction with other governmental agencies and services under different levels of seismic hazard.

One of the NSSP centers, the Centre of Seismic Knowledge Dissemination, carries on continuous activities for training the population in measures of protection against large earthquakes. This involves the production and demonstration of special training films on television; publication of special information concerning the rules of behavior before, during, and after an earthquake; addresses of the leading NSSP experts in different fields of seismic protection, from seismology to earthquake-resistant construction, on TV, radio and through the press; the NSSP instructors lecturing at schools and enterprises; regular reporting about the current seismic hazard level in the territory of Armenia via radio, newspapers, and television; and preparation of street training drills on seismic protection for the population in cities and other populated areas.

The draft law on the protection of the Armenian population against large earthquakes is now being prepared by the NSSP, and it will be submitted to the Parliament of Armenia in 1996.

One of the principal components of seismic risk reduction involves the training of highly skilled specialists in the fields of seismology, earthquake-resistant construction and other sciences related to earthquake preparedness. 1,6000 specialists in the field of civil construction and 48 engineer-geologists are now being educated at Yerevan State University, the University of Architecture and Construction, and American University of Armenia under the supervision of 40 professors. With the financial assistance of the American University of Armenia (founded in 1992), the funds allocated for the education of these students exceed those of other specialities. The faculty of the above- mentioned universities participates directly in the elaboration of construction codes for the Republic, conducts consultations, and takes part in the city construction project. As of yet, there is no association of engineer-builders or seismological association in Armenia.

6. Prompt response

Emergency preparedness activities in Armenia are coordinated by a special staff under the Government of the Republic. In parallel with this, the Organization of Special Governmental body-Emergency Managment Administration, including the entire Civil Protection System was started. Divisions of militia and fire brigades are submitted to the Ministry of Internal Affairs of Armenia and interact closely with the Civil Protection Staff in case of emergency.

As the Spitak earthquake showed, divisions of militia and fire brigades were of sufficient size but poorly-equipped with specialized means to render timely help to earthquake victims. In this regard, Army divisions usually provide more real help. Yerevan possesses a Prompt Emergency Actions Plan, but a large earthquake has its own distinctive features which are not accounted for in this plan. The gap in this field is filled by the Prompt Actions Plan developed by the NSSP.

The network of medical institutions ready to give urgent help in case of natural disaster is well developed in Yerevan.

The city provides the following alternative communication means in case of a disruption in telephone communications: radio, radio relay, and satellite communication.

When developing a plan of prompt and efficient actions of the Government and people in case of a large earthquake in Yerevan, the hard social and economic condition of Armenia becomes the main problem to be solved.

7.Some quantitative assessments of seismic risk for the city of Yerevan.

Seismic hazard zone of the Yerevan city is selected based on the disposition of active faults and historical earthquake sources which were known to cause destruction of the city in its historical past or are capable to damage its structures in future.

Our analysis (Balassanian, Manukian, 1994 [8]) shows that the source of strong Garni earthquake (M=7.0. 1679) is the most hazardous for the Yerevan city. This source is located at the Garni active fault, revealed by V.Trifonov and A. Karakhanian.

According to the available historical data the 1679 Garni earthquake was the most destructive in the centuries-old history of the Yerevan city, that was founded in 782 B.C. (Erebouni).

The extreme hazard of the Garni active fault and its source of strong earthquakes in particular, is aggravated by the seismic quiescence observed at the Garni source zone since 1989. (fig.3).

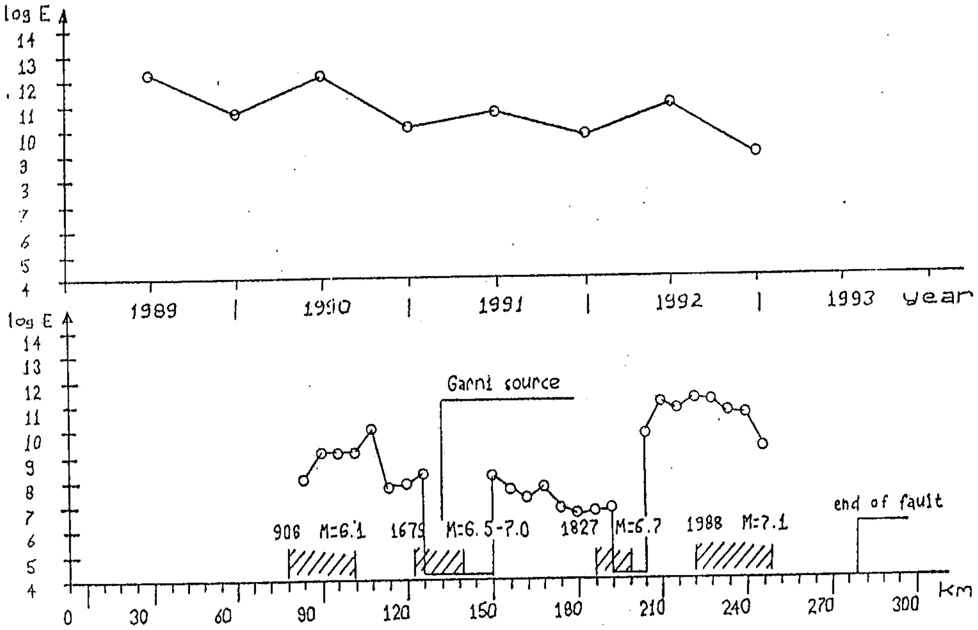

Figure 3. Seismic activity along the Garni fault from 1989 to 1993
(after the Spitak earthquake, 1988)

▨ - source of the large historical earthquakes

Reproducing the 1679 Garni earthquake scenario we obtained a general pattern of seismic risk related to destruction and human fatalities within the Yerevan city.

To solve the above task the three factors have been used as a basis:

- seismic hazard level in the Yerevan city estimated on the entire time series of seismic events within the zone hazardous for Yerevan;
- earthquake resistance of buildings and structures estimated accounting for ground conditions and design types;
- size of population residing in buildings and structures varying in earthquake resistance.

The risk of destruction for buildings and structures in the city of Yerevan is estimated employing criterion (2) used by S.Balassanian ($K_R = I_{hz}/I_{rl.r}$) [6, 4].

In so doing I_{hz} is defined as

$$I_{hz} = I_{in.\,hz} + \Delta\ I_{gr} \qquad (1)$$

where $I_{in.\,hz}$ - is the initial hazard (as intensity points); $\pm\Delta I_{gr}$- is the increment of intensity value for different ground types;

$$I_{rl.r} = I_{dn} + \Delta\ I_{constr.}, \qquad (2)$$

where I_{dn} is the design earthquake resistance of a structure (as intensity points) and $\pm\Delta I_{constr.}$ is the construction reliability (as intensity points).

The initial seismic hazard ($I_{in.\,hz}$) for the Yerevan city is evaluated on the macroseismic data given in Figure 4 from which it is clear that the Yerevan city is divided into two unequal parts by the Garni earthquake isoseism. The greater part is situated in the area we evaluated as intensity - VIII seismic hazard zone. Taking into account that in 1679 the Yerevan city was constructed in its central and northern parts, i.e. the structures were put principally on hard rock (fig.5) giving $\Delta\ I_{gr} = -1$ intensity increment, it is not difficult to suggest that the initial seismic impact ($I_{in.hz}$) in 1679 corresponded to intensity -IX in the zone defined by the isoseism and to intensity - VIII outside it.

Since the three ground types are mainly represented in the city of Yerevan (fig.5) the $\pm\Delta I_{gr}$ intensity increment has been defined at the cost of ground conditions as: $\Delta I= -1$, $\Delta I=0$ and $\Delta I=+1$ intensity for hard, wheathered and loose sand formation rocks, respectively.

Design seismic resistance of buildings and structures in Yerevan (I_{dn}) is subdivided into two categories:

- low-rise stone buildings (private construction) which are designed for intensity - VII without regard for ground conditions;
- all the rest design types (state sector construction) are designed for intensity VII for hard rocks and intensity VIII for other ground types.

The reliability of constructions ($\Delta I_{constr.}$) has been estimated based on the experience of the Spitak earthquake. In doing so, different constructions were assigned with fractional value intensity which is not generally accepted in construction practice, but appears useful in assessing the seismic risk of destruction for buildings and structures:

1. The most reliable large-panel buildings, frame and frame-braced (ΔI_{constr} = □ 0,5 intensity),
2. Reliable stone and masonry construction ($\Delta I_{constr} = 0$ intensity)
3. Non-reliable frame, frame-and-panel buildings constructed by floor-grade method ($\Delta I_{constr} = -\ 0{,}5$ intensity),

The results of assessing the seismic risk of destruction for buildings and structures as well as the seismic risk in relation to loss of lives for the case of repeated M7,0 earthquake in the 1679 Garni source are presented in Fig.3 and 4.

When integrally analyzing the maps presented in Fig.5 and 6 we notice that destruction greatest on the occupied area is expected in the southern part of the city (zones 9,10,12,and 13) while human fatalities are anticipated to be of moderate size, since low-rise private buildings are exposed to the risk of destruction here .

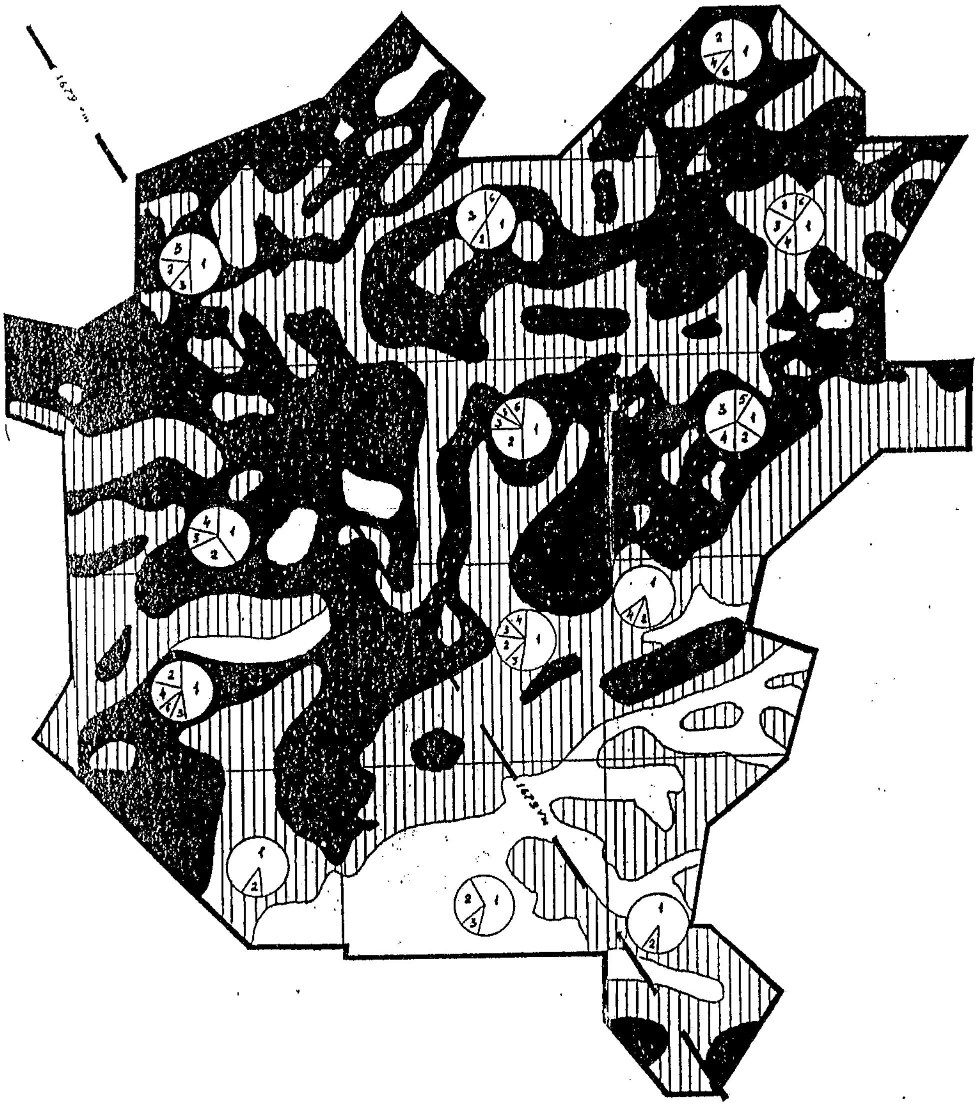

Figure 4. Scheme of Yerevan city indicating prevail ground according to seismic properties and constructive schemes of buildings

The category of grounding according to the seismic properties:
- ● 1. Rocky and large disintegrated rocks;
- ⦶ 2. Rocky weathering; coarse sand; clayey with J>0.5;
- ○ 3. Saddy unconsolidated; clayey with J>0.5.

Relation between the structural schemes of the buildings within the limits of the specified zone in the city of Yerevan

— 1679 VIII – Isoseism

The constructive schemes of buildings:
1. Low-storeyed stone houses (private);
2. Stone and complex constructions;
3. Large-panel;
4. Framework and frame-and-panelled;
5. Constructed by floor-grade method;
6. Frame and frame-brased.

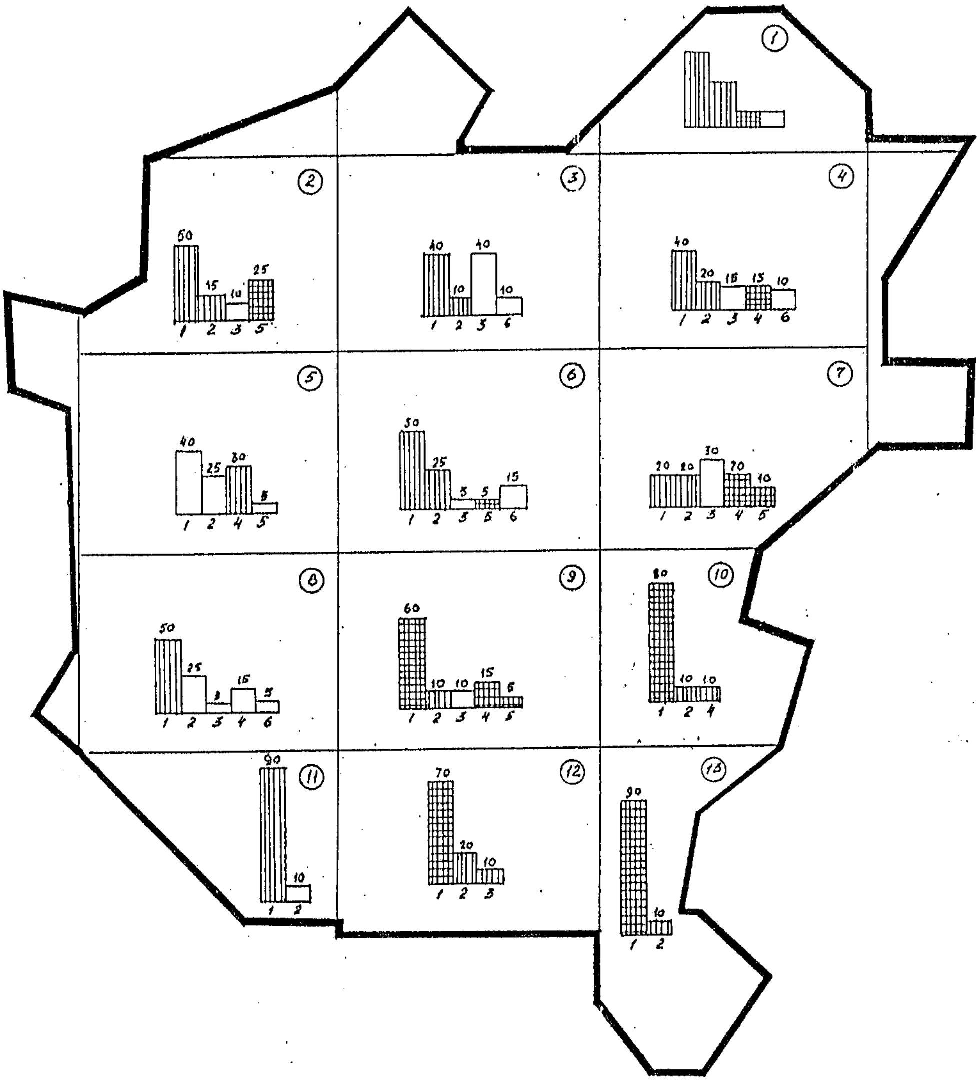

Figure 5. Map of the risk of different contruction type buildings in Yerevan city (design construction types 1,2,..., are indicated in percentage of the total number ob buildings in each square 1,2,..)

▭ 1. - no risk practically (K<1.06);
▥ 2. - moderate risk (1.05<K<1.1);
▦ 3. - high risk (K>1.1)

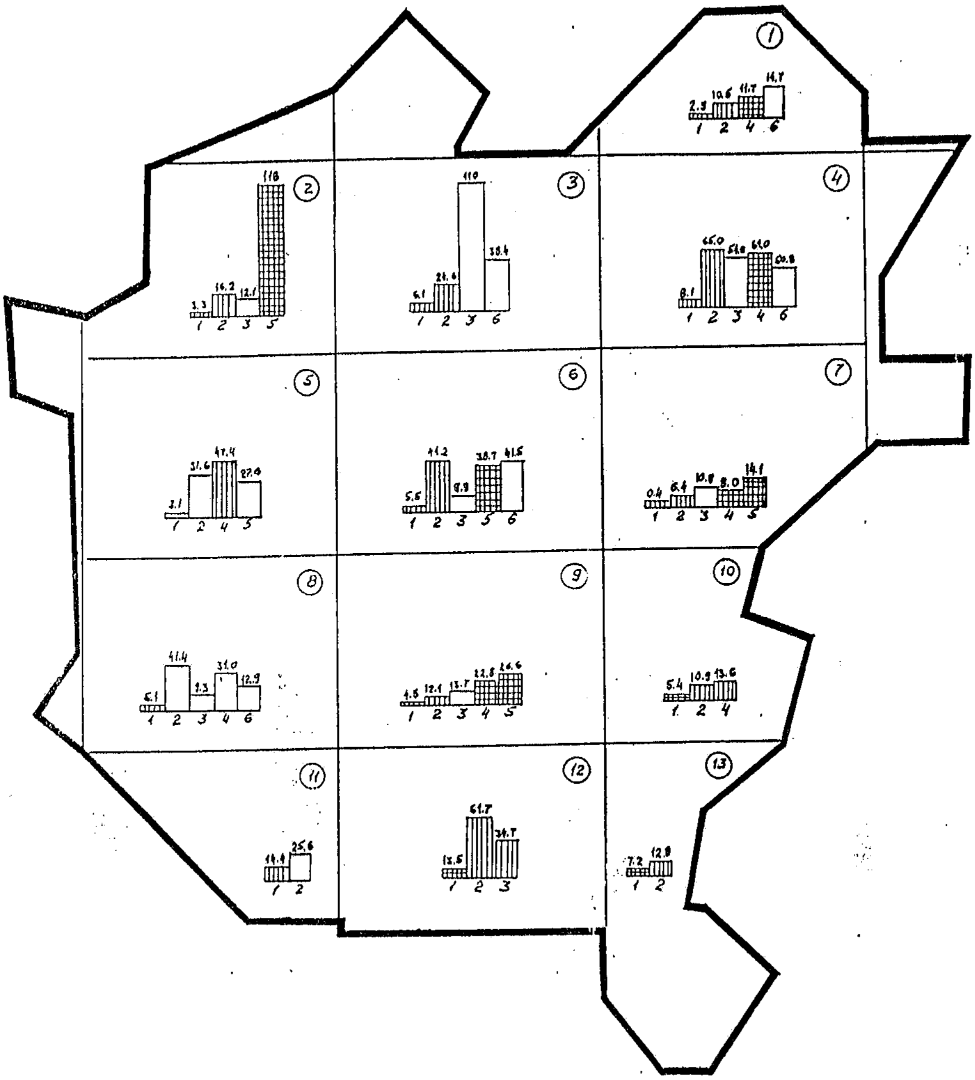

Figure 6. Map of the risk of people's death in Yerevan city
(number of people is indicated in the thousands of people
in eath design construction type 1, 2,..., in each square 1, 2, ...)

1. ▭ - no risk practically;
2. ▥ - moderate risk;
3. ▥ - high risk.

The most significant human fatalities are anticipated to occur in the north-western part of the city - zone 2, while destruction area will be relatively small here.

8. National strategy for seismic risk reduction in Armenia

After the disastrous Spitak earthquake and the institution of democracy in Armenia the government set about the task of seismic risk reduction.

For each state situated in a seismically active zone the solution of this most complicated problem is highly individual. It depends on physical and geological conditions determining the seismic hazard, the political system and economic capabilities of the state, the professional level of the specialists involved in the solution of the problem, the traditions of scientific schools, culture and the traditions of the nationals living in the territory.

In 1991, reasoning from the lessons of the Spitak disaster, the government of Armenia adopted the seismic risk reduction strategy developed by Prof. S. Balassanian. It consists of two main parts:

- organization of activities aimed at seismic risk reduction,
- a national program of seismic risk reduction.

In accordance with the first part of the strategy the following has been achieved:

1. The National Survey of Seismic Protection (NSSP) was created under the RA Government in 1991, i.e. there is now a state managed institution furnished with high governmental status adequate to the seismic risk reduction task which is vital to Armenia.
2. The head of the NSSP is directly subordinate to the RA Prime Minister, to urge rapid formation of the Survey and to solve the problem of efficient seismic risk reduction management in both the long and short term.
3. All research groups and organizations previously separated and thus not linked to each other by aims and tasks are joined within the NSSP structure.
4. Specialized centres closely interacting with each other and responsible for the development of all seismic protection components (from seismic hazard and risk assessment to earthquake-resistant construction code development, from population training to the organization of professional rescue teams) are formed under the auspices of the NSSP.
5. Horizontal interaction and vertical subordination schemes for the NSSP specialized centres, all of them working on the single task of seismic risk reduction, have been implemented.
6. The National Seismic Risk Reduction program has been transformed into at international program based on broad international cooperation with seismological and engineering seismology centres in the USA, Russia, France, Germany and other states. Well-organized activities in seismic risk reduction substantiate the success of the implementation of the National Seismic Risk Reduction Program, which among is main components involves the following:
    - seismic hazard and risk assessment,
    - seismic risk reduction.

As regards the field of seismic hazard assessment which consists of long short-term estimations according to the approved NSSP strategy, the survey has in the short run carried out following:

- completion of the seismic zoning map of the territory of Armenia on a 1:500,000 scale based on the National Data Bank compiled in the NSSP (the Bank includes all information related to the regional seismic regime from 5,000 BC, geological, geochemical and other special studies concerning Armenia and adjacent regions);
- creation of a system of current seismic hazard assessment that integrates the unique multi-level (providing underground, land and atmospheric observations), multi-parameter (registering more than 40 diverse characteristics of solid, liquid and gaseous phases of the lithosphere) National Observation

Network consisting of more than 150 stations linked by different communication means (from radio to satellite links) with the unified Centre of the NSSP for data acquisition, processing and analysis:

- an important stage of work in detailed seismic hazard assessment in the territory where hazardous facilities as, for instance, the Armenian Nuclear Power Plant, are located.

The Armenian NSSP seismic hazard assessment strategy differs from analogous activities in other countries to the extent it adds monitoring and assessment of current seismic hazard to the continuous long-term seismic hazard assessment in real time. This approach to the problem is oriented towards reducing the probability of the next sudden strong earthquake in Armenia.

In the field of seismic risk assessment the following was achieved for the first time in Armenia.

- A seismic risk map for the territory of Armenia was created based on the data of long term seismic hazard, the earthquake resistance of different types of structure, population density, etc.
- Detailed seismic risk maps on seismic risk for the territory of Yerevan city and other densely populated cities of Armenia were prepared.

As regards the seismic risk reduction:

- an important milestone in creating a new Earthquake Proof Construction Code for Armenia has been reached;
- new strengthening methods for typical buildings and structures which have been successfully tested in the North of Armenia, i, e, the former Spitak earthquake disaster zone, have been elaborated;
- activities for training the population in case of another severe earthquake have begun;
- a special rescue team has been formed;
- a system of interaction with the government according to different levels of seismic hazard is being developed;
- a legislative basis for the protection of the population in the case of severe earthquakes is under preparation.

8.1. THE STRATEGY AIMED AT REDUCTION OF SEISMIC RISK OF DESTRUCTION OF BUILDINGS AND STRUCTURES IN THE CITY OF YEREVAN.

From the data presented in Fig.6 it is seen that a great number of buildings and structures is exposed to the seismic risk of destruction in the territory of the city of Yerevan.

The analysis of obtained data has shown that about 23 km^2 of the city area, that comprises 15 percent of the total, is represented by the zones of high seismic risk. About 1516 buildings where 327 thousands of people reside (i.e. 26 percent of the Capital population) have been constructed here.

Taking into account that buildings noted for moderate seismic risk are subject to destruction, too, it is not difficult to suppose that the scope of destruction and loss of lives could significantly increase the values - 1516 buildings and 327 thousands of people.

To reduce the risk two versions are possible:

- to rebuild anew vulnerable buildings and structures;
- to reinforce non-earthquake resistant structures.

Considering the present economic difficulties in Armenia it is impossible to follow the way of rebuilding the vulnerable structures.

It is likewise impossible to reinforce them in full measure since this project will be a too expensive one.

Reasoning from the above the strategy of stage-by-stage strengthening of structures which are non-resistant in seismic respect has been developed in the NSSP. It resides in the following:

- the built up areas with the most increased risk of destruction should be identified;

- vital importance objects of the Republic as well as those design solution types to which high number of population at fatal risk is referred should be identified within the limits of builtup areas with the most increased risk of destruction;
- among the design construction types imposing risk rupon great number of people those for which efficient and relatively inexpensive retrofitting methods are known should be selected;
- the buildings which are in the worst technical condition most often due to violation of maintenance rules should be reinforced first of all those selected on the three forementioned characteristics.

Based on the above strategy and according to the data given in Fig. 5, 6 it has been established for the city of Yerevan that:

- areas of the most increased risk of destruction are built up with low rise stone masonry private structures, masonry and complex structures; frame and frame-panel buildings as well as those constructed by lift slab method;
- stone masonry and complex construction buildings, structures performed by lift slab method as well as frame and frame-panel buildings refer to the design types used for vital importance objects of the Republic and for the housing where a great number of population is exposed to fatal risk;
- effective and relatively inexpensive retrofitting methods are known for the selected construction types of masonry (including complex construction) and frame, frame-panel buildings.

The total number of stone masonry (as well as complex structures) 3-16 storeyed buildings with increased risk of destruction is equal to 840 while that of frame 3-6 stroreyed buildings is 303.

First of all, 115 frame and 103 stone masonry buildings should be reinforced reasoning from their state due to maintenance.

To reinforce these buildings 65.000.000 USD will be required accounting for about 300.000 USD per 1 building (the data are obtained in the office of the World Bank earthquake zone reconstruction project).

8.2. THE METHODS OF INCREASING THE EARTHQUAKE RESISTANCE OF EXISTING BUILDINGS DEVELOPED IN NSSP AND IMPLEMENTED IN ARMENIA

The conventional methods of increasing the earthquake resistance are not applicable in Armenia because they require the eviction of dwellers. That is why two methods of increasing the earthquake resistance of existing buildings were developed in NSSP. First - by means of an additional isolated upper floor (AIUF) [10] and second - by means of seismic isolation [11]. Both methods were implemented in Armenia in the city of Vanadzor.

The AIUF represents the dynamic vibration damper. It is known that vibration damper is the pendulum specially designed and rigidly connected to the structure, vibration of which should be decreased. In our case AIUF is also a pendulum but in the form of additional floor constructed on the top of the building. The mass of the pendulum is the mass of the whole additional floor, and the spring of the pendulum is represented by laminated rubber bearings (LRB) by means of which the additional floor is connected to the building.

A special structure of connection of the AIUF to the building was developed and designed. The building itself is the frame structure with the distance between columns 6x6 m. There are 16 columns in the plan of the building. All columns are passing through the slab of the ninth floor on the height of 1.5 m. It is assumed that LRB will be installed on each column. With this in mind, all 16 columns on the top of the building were taken into steel jackets with the height of 1.5 m so that the horizontal part of the jacket in the size of 414x414 mm represented steel plate with the thickness of 25 mm, to which LRB was bolted. All 16 columns were connected to each other by means of steel trusses. Thus a rigid structure is created to transfer the forces from AIUF to the building. In essence, the additional floor itself also represents the rigid structure, which during the earthquakes being supported by LRB practically has no deformations. Consequently, the suggested method allows not only to increase the seismic resistance of the buildings by damping of vibrations, but also to add a useful space.

The AIUF represents a steel frame structure with the same number of columns in plan as in the building. The base of each column is a steel plate bolted to the upper flange of LRB. All steel columns of AIUF also were connected to each other by means of steel trusses. On the level of upper belts of trusses a R/C slab is designed using precast panels with the thickness of 22 cm. The plane roof and the exterior walls of AIUF were designed using light "sandwich" type elements.

The reduction of shear forces in the building with AIUF takes place because of increase of the period of vibration of the whole system (building plus AIUF) and decrease of the first mode vibration coefficients. However, new type of second mode of vibration appears and becomes prevailing and as a result AIUF oscillates in anti-phase related to the building. All these factors are leading to the reduction of shear forces and horizontal displacements.

For the experimental approval of the proposed method, dynamic tests of R/C 9-story full-scale frame building, before and after mounting the AIUF, were carried out. The tests allowed to prove that AIUF decreases the shear force of the first story 1.7 times and the displacement of the ninth story 2.1 times. Consequently, acting as vibration damper, AIUF brings to increasing of the building earthquake resistance.

Development of seismic isolation systems is a new line of inquiry in Armenia. In the last 10-15 years considerable study is being given in developed countries to the problem of putting the laminated rubber bearings (LRB) into practice as isolation device. Due to its damping and dissipation properties LRB can filter out ground motions over a sufficiently wide range of frequency characteristics. Vibration mode of the structure, in turn, becomes simpler and approximates that of rigid body, relative deformations within the height of each story being minimized, thus precluding the possibility of damage to occur.

The system of base isolation for increasing the seismic resistance of an existing 5-story masonry residential building was developed. The present project was developed in cooperation with the MRPRA. Design, manufacturing and delivery to Armenia of the LRB was done by the MRPRA. Design of the whole seismic isolation system was carried out by the NSSP. In all, 60 LRB designed by the MRPRA at maximum horizontal displacement of 13 cm according to the seismic code of Armenia, and under vertical loads in the range of 58-88 ton, are used for base isolation of mentioned building. LRB of two types, namely the "soft - S" and "hard - H" ones, depends on value of the vertical loads are applied. Overall dimensions of both type LRB are the same: height of 196 mm and diameter of 380 mm.

The main idea is that within the limits of basement floor of the existing building R/C beams are designed with gradual building up on two levels along all bearing walls. In parallel with building up of beams the LRB being installed between them. Following steps of all operations of constructing the seismic isolation system were performed. At step 1 a hole with approximately 1.6 m height and 1.2 m width in the wall bored, the reinforcement of the lower level beam, as well as the base for the first LRB are mounted. At step 2 a part of the lower level beam concreted, the first LRB and the reinforcement of upper level beam are mounted. At step 3 a part of the upper level beam concreted, a hole in the wall for the second LRB bored, reinforcement for lower level beam built up, and the base for the second LRB mounted. At step 4 the lower level beam concreting continued, the second LRB mounted, the reinforcement for the upper level beam built up. At step 5 the upper level beam concreting continued, a hole in the wall for third LRB bored, reinforcement for the lower level beam built up, and the base for the third LRB mounted and so on. The design presupposes the beams of the lower level to be connected to the existing foundations. With this purpose in view, on the top surface of the foundations along all axes of building, holes of 30 cm depth, spaced 70-80 cm, are bored, in which anchor rods of diameter of 18 mm are mounted using epoxy glue.

The present method has been developed with consideration of those technological possibilities of construction industry in Armenia. Its advantage is in the relative ease of carrying out technological operations of reinforcing and concreting of R/C beams of the seismic isolation system of both levels, as well as in the possibility to control the accuracy of mounting the LRB. Upon completion of all LRB the parts of existing walls between the beams of both levels are cut in an orderly sequence, which results in transferring all the load from the building to the LRB.

9. Conclusions

Over the centuries - old history Armenia has suffered numerous destructive earthquakes that caused tremendous damage to the nation.

The territory of Armenia was urbanized, especially in Soviet days, and built over with low cost buildings and structures with earthquake resistance level that does not match the seismic hazard level [1]. Owing to the above seismic risk in the territory of Armenia has increased drastically.

The disastrous 7 December, 1988 Spitak earthquake shook Armenia and the whole world by the scope of destruction and loss of lives - 25.000 people died, 50.000 were injured and 500.000 lost their homes. The Northern Armenia was eliminated actually in total.

The best worldwide-known experts from 20 countries who gathered at the October, 1993 International Conference in Armenia dedicated to the 5th Anniversary of the Spitak earthquake and held in memory of its victims [2] came to conclusion that the territory of Armenian Upland was subject to persistent sharp activation started with the 1976 Chaldran earthquake in Turkey (see Appendix).

What this means is that new ordeals are in store for Armenia and they might turn to be fatal for the nation in case strong earthquake repeated in the region of Yerevan. The probability of such an event is rather real, since once Yerevan has already been destroyed by the 1679 strong earthquake.

Taking into account that the type of structures, design standards, construction materials and practice of construction in Yerevan are the same as in the destroyed cities of Northern Armenia and almost 40 percent of the republican population is concentrated in the Capital, it is not difficult to suppose that scope of probable disaster would be so great that no help regardless where it comes from could prevent the elimination threat for Armenia as a viable state.

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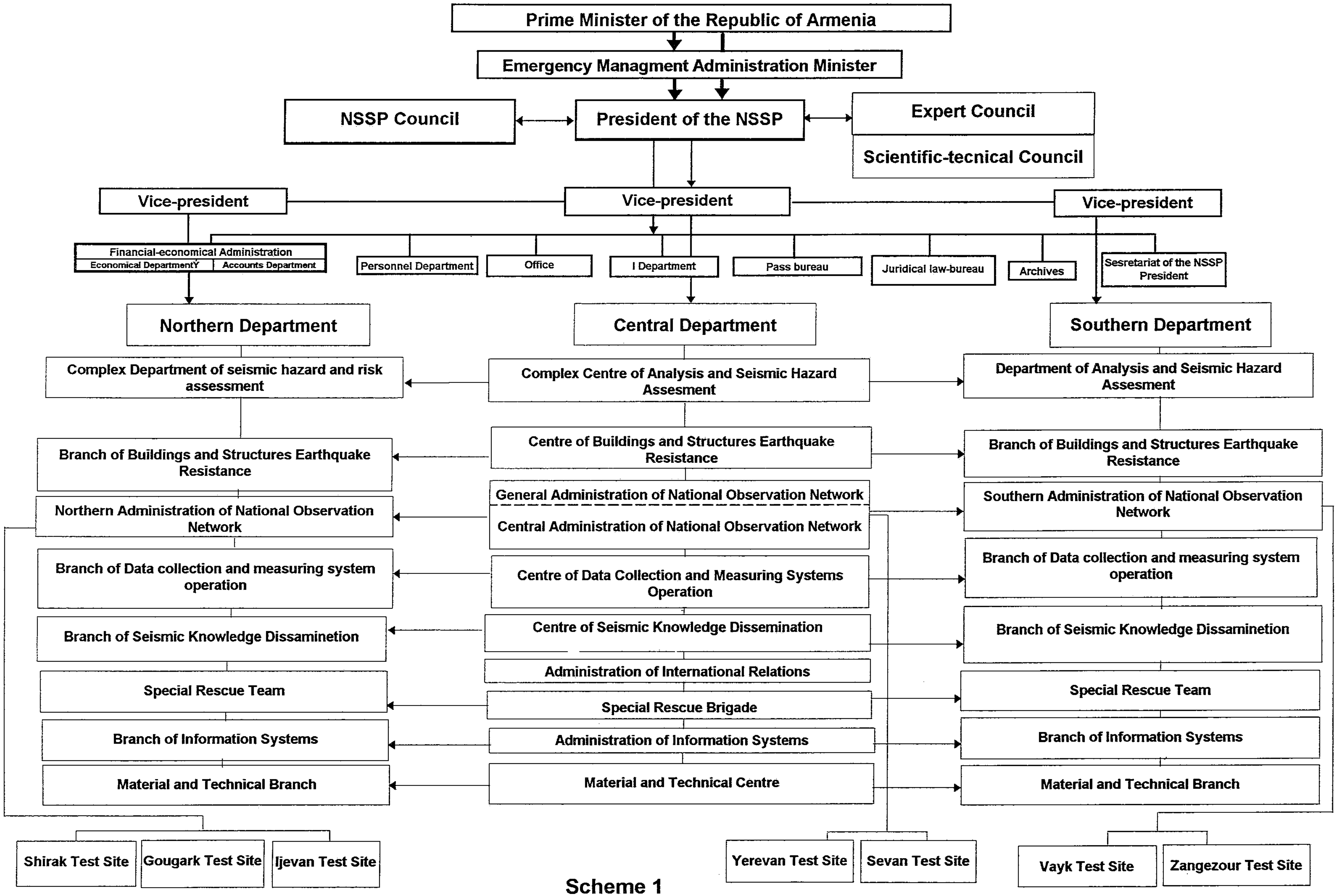
THE STRUCTURE OF THE NATIONAL SURVEY FOR SEISMIC PROTECTION OF THE REPUBLIC OF ARMENIA



Scheme 1