

EARTHQUAKE ENGINEERING EVALUATIONS AND RECONSTRUCTION IN ARMENIA

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I. INTRODUCTION

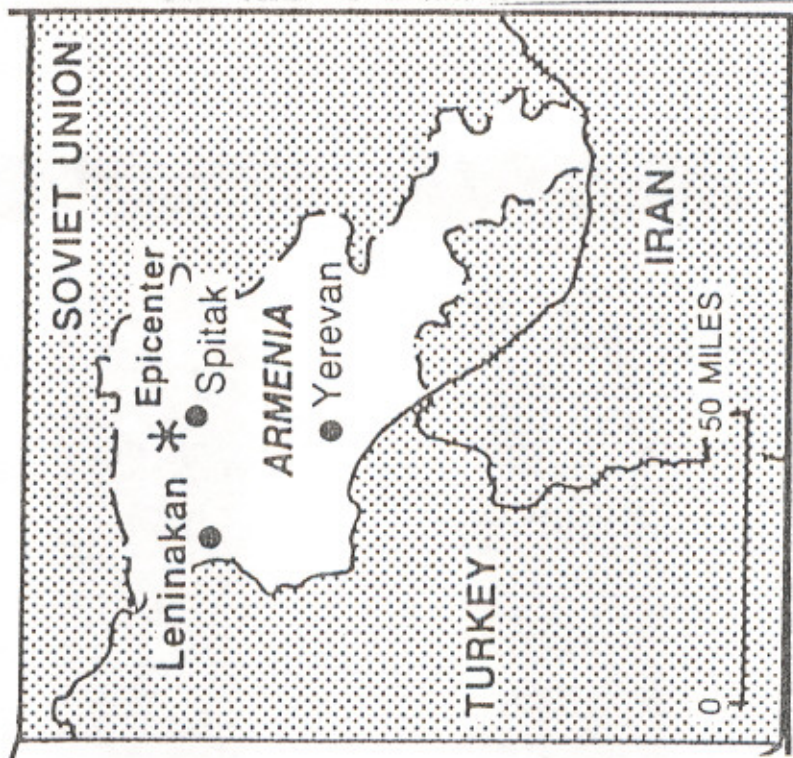
The result from any major earthquake such as the 1988 Spitak earthquake in Armenia or the 1990 Manjil earthquake in Iran is a human tragedy. Notwithstanding, earthquakes provide opportunities for scientific evaluations leading to: better understanding of seismo-tectonics of the devastated region, technologically sound plans for reconstruction, and improved construction practices.

Following the 1988 Spitak earthquake the authors embarked on an evaluation of the damages incurred from the earthquake. Their scientific effort was funded by the National Science Foundation of the United States government. The purpose of their investigation was to study and evaluate the lessons to be learned from the Spitak earthquake that could help mitigate the effects of future earthquakes.

This paper provides a summary report on the seismicity of Armenia, and on the evaluations of the damages caused by the Spitak earthquake. In addition, comments are made on the reconstruction technology, policy, and programs; and recommendations are provided regarding the earthquake engineering practice and reconstruction in Armenia.

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II. OVERVIEW OF THE 1988 SPITAK EARTHQUAKE

On Wednesday December 7, 1988 an earthquake of magnitude 6.9 occurred in the Northwestern region of Armenia. The earthquake generated a fault which initially was thought to be about 8 kilometers. Months after the earthquake, it was revealed that the fault extended 40 kilometers in a Northwest and Southeasterly direction passing near the town of Spitak. Because of its proximity to the fault, the town of Spitak (population about 20,000) was totally devastated. In the city of Kirovakan (population about 200,000) which is located 15 kilometers from the fault, except for one region where about 40 buildings collapsed, there was little damage in the city. Approximately 30 kilometers from the fault, the city of Leninakan (Kumayri) (population about 270,000), was seriously devastated. Overall, about 40 to 50 thousand people lost their lives, and close to 500,000 people left homeless from the Spitak earthquake. In addition, thousands of buildings collapsed or were damaged beyond repair. The damages incurred, specially those in Leninakan (Kumayri), gave rise to questions regarding the quality of the concrete, the design practice, and the effect of the local soil conditions upon building damages.

III. SEISMIC EVALUATIONS

In this section a brief summary of the results obtained by the authors from their studies on the seismicity of the region and earthquake engineering evaluations is presented.

III.1 Seismicity and Earthquake Magnitude

Scientists in Armenia have completed a catalogue of historical earthquakes dating as early as 138 A.D.. Figure 1 shows the magnitude and the date of these historical events within the present Armenia. It is noted that the scarcity of the data for the past many centuries relative to the last century is probably due to inadequate reporting and documentation of historical events. For this reason, the analysis of the frequency of occurrence of earthquakes in Armenia was done considering first the entire historical record shown in Figure 1, and then the record of earthquake occurrences since 1900. Figure 2 shows the return period of the different magnitude earthquakes in Armenia. Based on this analysis of the local historical seismicity, it is concluded that the return period associated with the Spitak (magnitude 6.9) earthquake of 1988 is most likely 100-300 years if emphasis is placed on the

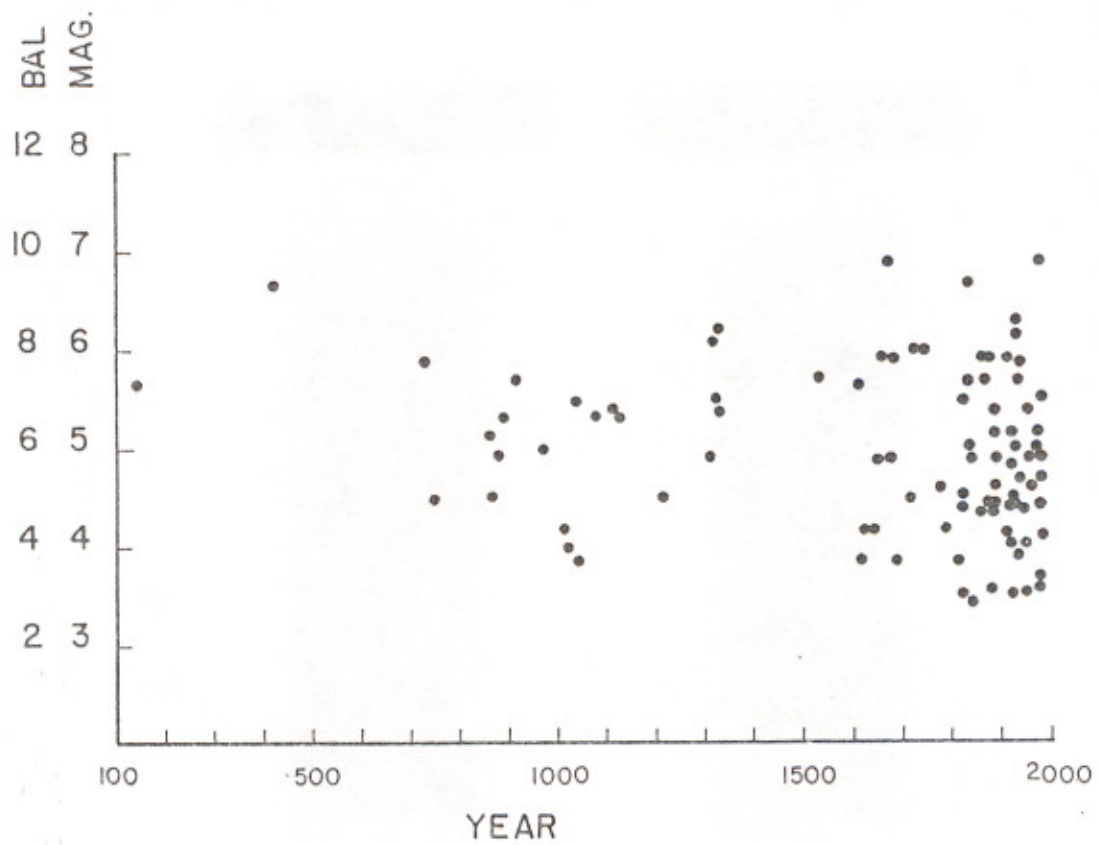


FIGURE 1

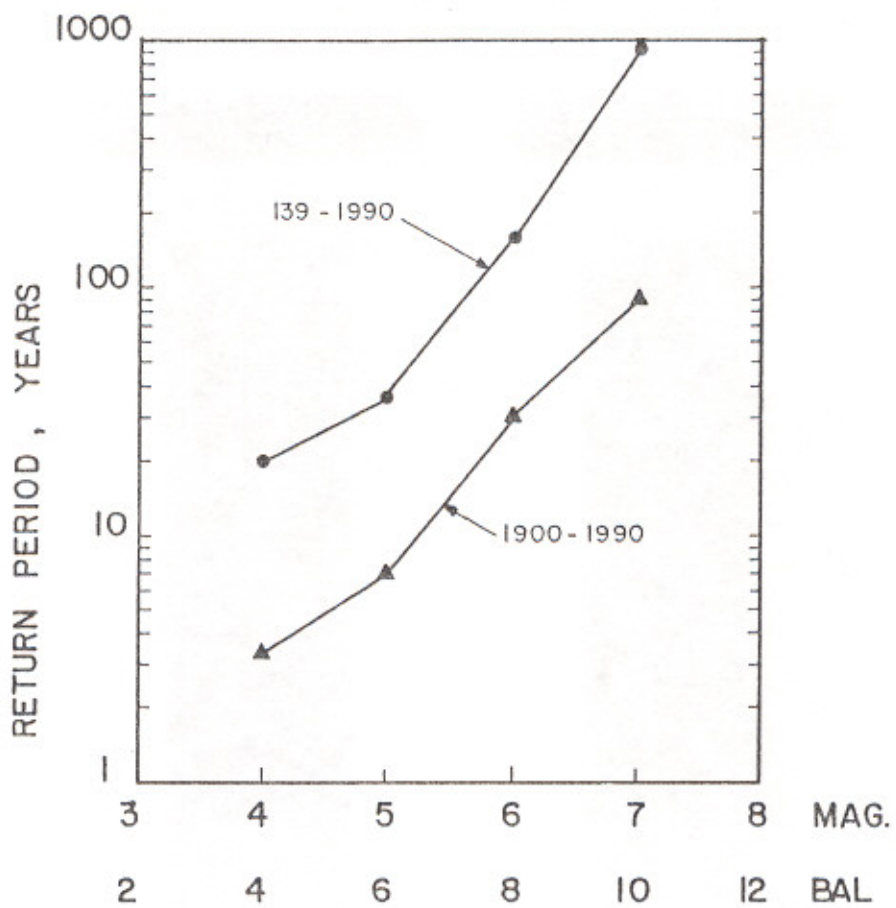


FIGURE 2

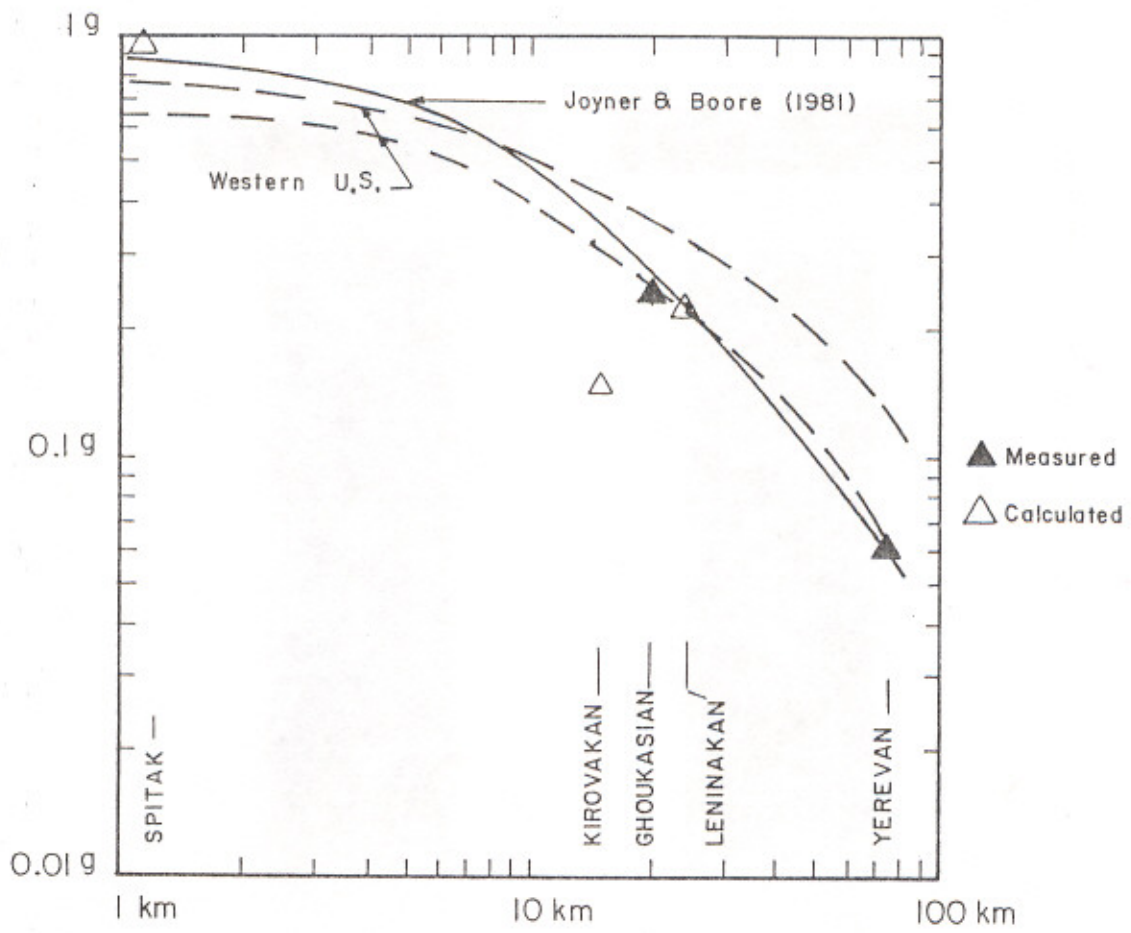


FIGURE 3

more recent, and what appears to be more complete, seismic activity record for Armenia. In addition, the historic seismicity record of the wider region including historic Armenia and Northwestern Iran, as well as geologic evidences strongly suggest that, an earthquake having a magnitude in the range of 7.0 to 7.5 can be expected in Armenia, having a return period of about 200 to 500 years.

III.2 Ground Motions

During the Spitak earthquake, the ground motions were scientifically recorded only at two locations (in Ghoukasian and Yerevan). Ground motions in other cities were calculated by the observations of the dynamic response and motions of grave markers in different cemeteries. Model tests were also performed on a shaking table to estimate the limiting ground accelerations that selected grave markers of interest, (i.e. those that overturned and those that did not), experienced during the earthquake. Figure 3 presents the peak ground accelerations in different cities during the Spitak earthquake. It is noted that except for the motions in Kirovakan all of the data show ground acceleration attenuation with distance from the fault very similar to that established by data obtained from earthquakes in California. It is concluded that the ground motions in Armenia attenuate with distance away from the fault quite rapidly compared to more slower attenuation observed in the Eastern part of the United States. It appears that the ground motions in Kirovakan were smaller than those expected from a magnitude 6.9 earthquake. A speculative reason for this anomaly could be that the regional topography had major influence upon ground motions and wave propagations. Hence, Kirovakan was protected by the mountains that exist between the fault and the city.

III.3 Ground and Building Response

It is now well recognized by the earthquake engineering profession that during earthquakes soils overlying bedrock can increase the effect of the ground motions upon building response thus exasperating damages. To evaluate the influence of the soil conditions upon the ground motions, analytical studies were performed. Figure 4 shows schematically the approach in which the recorded ground motions on rock are used and the propagation of the generated waves from rock to the ground surface is analyzed. The resulting motions at the ground surface and their effects upon structures are compared with corresponding values on rock.

In the site response analysis described above, the determination of the proper values of the

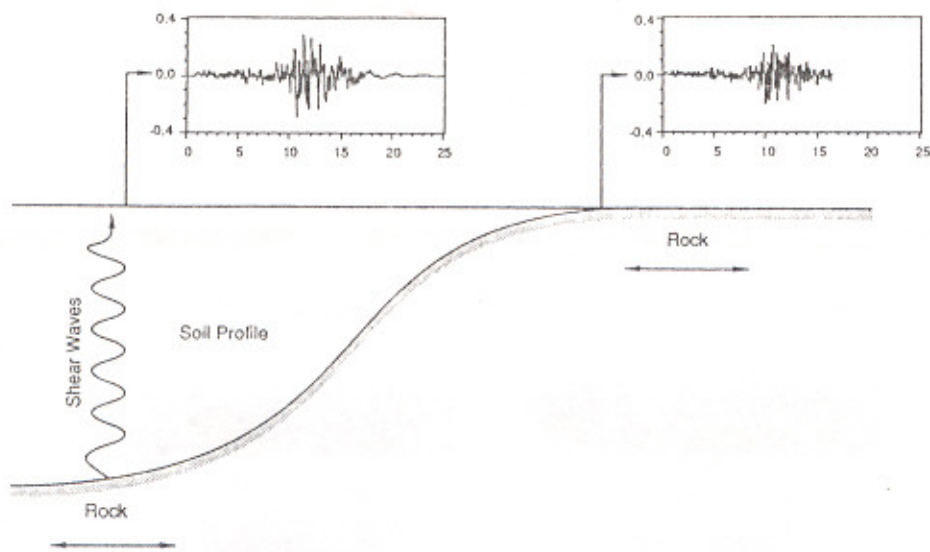


FIGURE 4

RATIO OF ACCELERATION RESPONSE SPECTRA
AVERAGE

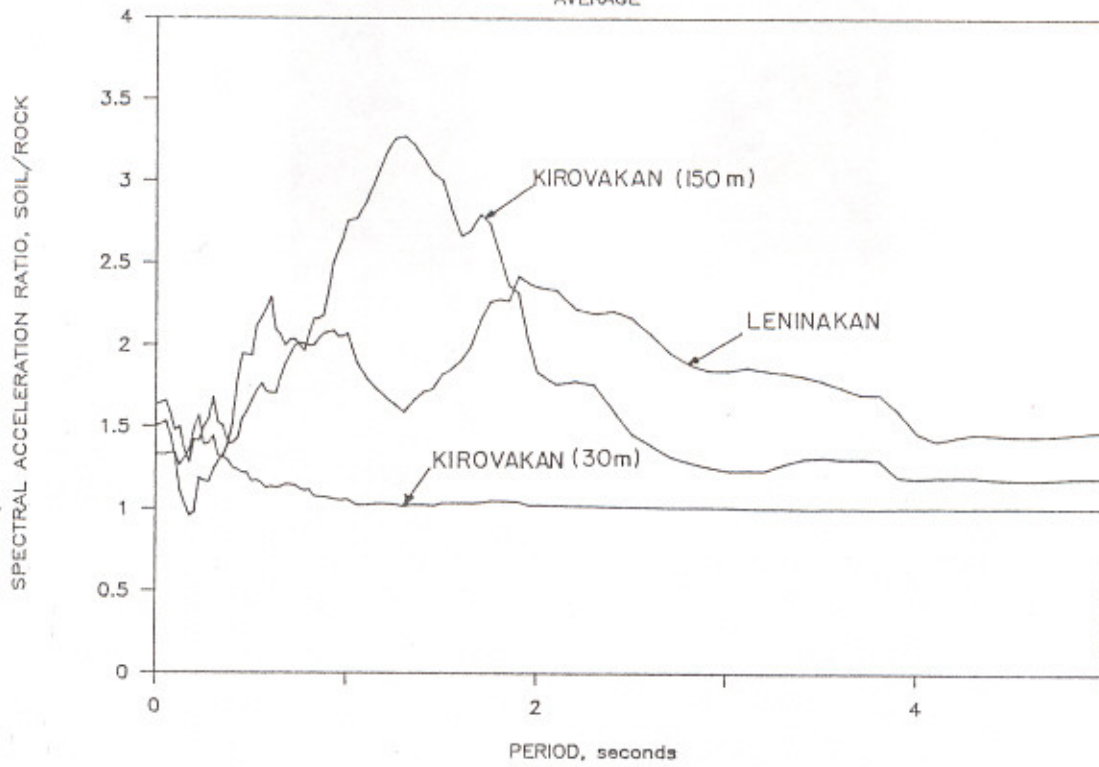


FIGURE 5

parameters that define the properties of the soils, and their thicknesses is very important. In the studies for Kirovakan and Leninakan (Kumayri), the results of geologic, geophysical and geotechnical investigations were utilized. In addition, special field and in-situ testing equipment were transported by the authors from the United States to Armenia to obtain relevant soil properties. Figure 5 presents a typical set of results obtained from the analysis performed to determine the effect of the ground soils upon building damages caused by the earthquake. The vertical axis shows the amplifying effect of the soil upon structural response, while the horizontal axis depicts the natural period of a series of structures. It is noted that most of the 4 to 9 story structures that collapsed or were severely damaged in Armenia, had a natural period range between 0.4 to 1.0 second. Based on the results of the site response analysis made, the following conclusions can be made.

- * In Kirovakan, where most of the city is on 30 meters or less of firm soils, the site effect has been minimal and consequently, damage was little. In one area, where there is about 150 meters thick stiff soils deposit, the site may have amplified the elastic building response by a factor of 2. In this area the building damages were devastating.
- * In Leninakan (Kumayri) which is founded on about 350 meters of lake and river deposits, the influence of the site has again been important (factor of about 2). Damages were also devastating.
- * Since the 4-5 story stone buildings and 9 story precast frame and panel buildings in Kirovakan founded on firm ground and rock survived without collapse, it is concluded that these structures must have had some inherent strength against earthquakes. However, the same buildings founded on thick soil deposits in Kirovakan and Leninakan (Kumayri) were responsible for the major devastations. Therefore, these buildings had, at least, one half the strength required during the magnitude 6.9 earthquake.
- * The above mentioned buildings founded on firm ground or on 100 to 400 meters of alluvium can adequately resist an earthquake with magnitude of up to 6.0. This has an important implication on the need for strengthening similar existing buildings in Yerevan.
- * It appears that the most important reason for the devastation caused by the Spitak earthquake was that the building design practice followed in Armenia was inadequate and did not provide the necessary resistance in the structures to safeguard against a magnitude 6.9 earthquake.

IV. RECONSTRUCTION

Based on the seismic evaluations completed by the authors and also based on their observations and knowledge gained through their interaction with Armenian scientists, engineers, planners, and architects the following recommendations related to reconstruction are provided.

IV.1 General Recommendations Regarding Building Structures

- * The earthquake magnitude for design of new structures in Armenia should be at least 7.0 on the Richter scale. (Intensity 9 to 10 Bal on rock)
- * Ground effects need to be properly considered in building design practices. In doing so, site exploration and in-situ determination of the soil properties are essential tasks to be performed.
- * Repair and strengthening of many existing buildings can be more cost-effective than just outright demolition and replacement.
- * The building design code for Armenia, and particularly the sections regarding the seismic provisions, needs to undergo major improvements.

Other Facilities

- * Bridges, roads, railways, and other essential transportation facilities should be evaluated and strengthened as deemed necessary. For example: the Nalband railway station totally collapsed during the Spitak ($M = 6.9$) earthquake. The results from field measurements of the soil strength properties together with earthquake response analysis of the station, indicate that this station may again fail and disrupt services during a smaller magnitude ($M = 6.0$) earthquake in the future.
- * Strengthening measures should also be taken for vital structures such as earth dams, embankments, water towers and distribution facilities, hospitals, electrical generation plants, etc.

IV.2 Lessons from Iran

In August of 1990 upon the invitation of the Iranian government the authors travelled to Iran to assist the local engineers and geologists in their evaluations of the June 21, Manjil earthquake in Iran. Since, both Northwestern Iran and Armenia are in the same tectonic region, many similarities could be observed between the two earthquakes from the seismological and earthquake engineering points of view. However, in the area of reconstruction there are significant differences between the Armenian and Iranian programs. The following comments are made regarding the reconstruction plans and program in Iran.

- * The reconstruction process is well planned and comprehensive.
- * The role of the Iranian government is limited to providing design specifications, infrastructure, construction supervision, building material, and loans.
- * The government recognizes that participation of the people in rebuilding is essential. People will be responsible for rebuilding their own homes specially in the rural areas. Private ownership is an essential part of the plan.
- * Towns and cities will not be relocated unless dictated by technological reasons.
- * Reconstruction will start after earthquake evaluations and field investigations are completed.

V. FINAL COMMENTS

More than two years have passed since the devastating earthquake hit Northern Armenia. Reconstruction since then has been very slow and plagued with problems, difficulties, and challenges of various nature. Yet, there is a great need to:

- * Continue recognizing that reconstruction of the earthquake devastated region must be a major priority for Armenia.
- * Collaborate with international communities and utilize technological and financial resources to accelerate the progress of reconstruction.
- * Use judiciously the construction materials and labor, avoiding wastes.
- * Actively involve in construction, the people who are suffering from the consequences of the earthquake. In this context, there are particular lessons to be learned from the Iranian reconstruction experience.