EVALUATION OF THE EFFECTIVENESS OF RISK REDUCTION MEASURES FOR EARTHQUAKE ASSOCIATED GEO-HAZARDS IN TEHRAN

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ABSTRACT

Tehran is located in a seismic prone zone in north central part of Iran along Alpine-Himalayan orogenic belt. The city has experiences many destructive earthquakes in its history and it is expected to be affected by strong earthquakes in future as well. Considering the geological setting of this city, it is expected that any potential earthquake in Tehran may associate with some geological instabilities. In this paper, the potential geo-hazards that may associate with earthquake in Tehran including ground motion amplification due to site effects, slope instabilities (landslides and rock-falls), liquefaction and land subsidence due to collapse of existing Qanats (underground irrigation tunnels) will be introduced. In addition some measures to reduce the potential impacts of such hazards will be presented and discussed. Furthermore, the criteria for controlling the growth of the city towards hazard zone that have been reflected into the Master Plan of Tehran will be also introduced.

INTRODUCTION

Tehran, the capital of Islamic Republic of Iran, is located in a seismic prone zone along the Alpine-Himalayan Orogenic belt. As shown in Figure 1, the city has been surrounded by several active faults and experienced numbers of strong earthquakes in its history. Seismologists believe that a strong earthquake may occur in Tehran during the coming years. On the other hand, most of the researches carried out during the recent years; depict the high vulnerability of buildings and infrastructures to potential earthquakes. Therefore, in case of occurrence a strong earthquake, considerable loss and damage can be expected (CEST and JICA, 2000).

Besides of vulnerability of the built environment in Tehran to potential earthquakes, geological hazards such as liquefaction, landslide and rock fall which can be induced or triggered by earthquake motions; may also increase the damages of urban fabrics in the city. Considering the geological setting and topographical condition of Tehran and this fact that many buildings in the city are constructed on unstable ground, and based on what experienced in recent earthquakes in Iran (especially in Manjil, 1990 and Firouz Abad–Kojour, 2004 earthquakes), it seems that the potential impacts of geo-hazards associated with earthquake in Tehran can be destructive.

Ground motion amplification due to site effects, slope instabilities and rock-falls, ground subsidence due to collapse of underground openings and Qanats (underground irrigation tunnels) and even liquefaction are some of the main features of geo-hazards that can be expected at different parts of Tehran.

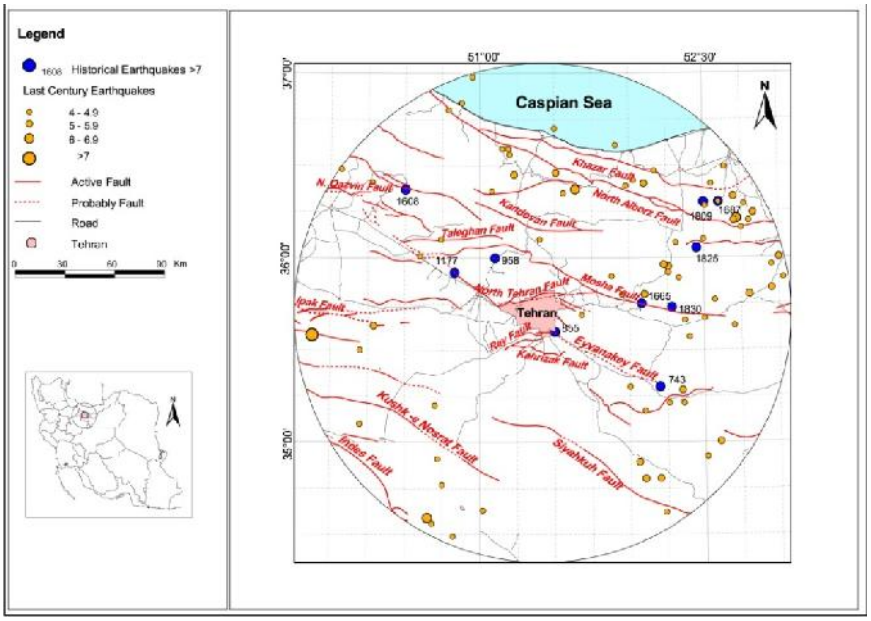

Figure 1. Main faults around Tehran and the location of historical and recent earthquakes around the city in 150 km radius (Amini Hosseini and Hosseini, 2007)

In order to reduce potential impacts of geo-hazards associated with earthquakes in Tehran, some criteria have been developed by IIEES and approved by Tehran Municipality and Ministry of Road and Urban Development of Iran (Jafari and Amini Hosseini, 2004). These criteria then were reflected in master and comprehensive plans of the city. A series of guidelines were also provided on how to implement these criteria to prevent and reduce such hazards according to their types and conditions. Furthermore, some applicable methods of remediation or ground improvement were also proposed along with guidelines.

In this paper, having a look on these criteria, the challenges of applying them in practice and their effectiveness in reducing the risk of geo-hazards in the city, after about 10 years from their implementation, will be presented and discussed. In addition, the importance of integrating socio-economic conditions of urban fabrics with the physical aspects as well as potential hazards for formulating any criteria for renovation vulnerable urban fabrics will be shown. The results of this study can be applied in other cities having similar conditions.

GEO-HAZARDS ASSOCIATED WITH EARTHQUAKE IN TEHRAN

Geological and topographical setting of Tehran is very complex and diverse. In northern parts of the city many buildings and infrastructures were constructed on steep slopes along Alborz Mountain Ranges (figure 2). Therefore, it can be expected that in case of occurrence of an earthquake, many of such buildings will be damaged by landslides or rock-falls. The impacts of such instabilities have been reported in many earthquakes in Iran earlier, some listed in table 1. For example in The Firouz Abad-Kojour Earthquake that occurred on May 28, 2004 close to Tehran, about 32 persons among 41 total casualties lost their lives because of landslides and rock-falls.

Table 1. Some of the slope instabilities triggered by earthquakes (Jafari et al., 2000)

Place	Year	Type	M	Effects
Ray	958	Landslide	7.7	Burial of villages
Frame	1127	Landslide	6.8	Damage to villages
Damavand	1830	Rock Fall	7.1	Road Blockage
Talarood	1935	Landslide & rock-fall	5.8	42 killed by landslides
Bandpey	1957	Landslide & rock-fall	6.8	Road Blockage
Manjil	1990	Landslide & rock-fall	7.3	Burial of villages and road blockage
Firouz Abad- Koujour	2004	Landslide & rock-fall	6.2	32 killed by landslides

Figure 2. Construction of vulnerable structures on unstable slopes in North of Tehran

Besides of landslides, due to high level of underground water table and grainy deposits in some parts of Tehran, there is the risk of liquefaction in these places. However, there is no evidence of liquefaction in the history of Tehran, but recent studies depicted that due to increase of table, there is the possibility of such hazards at local levels in the central parts of Tehran.

Figure 3-left depicts the areas susceptible to slope instabilities and liquefaction in Tehran. It can be observed that the risk of landslides and rock-falls are limited to the northern part of the city, while the risk of liquefaction is limited in some central parts of Tehran. Therefore, the city managers should consider such risks for issuing any permit of constructions in these places.

The other geo-hazard feature that may increase the damages and casualties of potential earthquake in Tehran is the ground motion amplification due to the difference in geological setting in Tehran basin. In some parts of Tehran the building were constructed directly on bed-rock, while in some places they are built on thick sediments with hundreds to thousands meter depths. In such condition, there is a high possibility of ground motion amplification due to site effects. Figure 3-right depicts the results of the last studies carried out to determine the potential of ground motion amplification. As can be observed in this figure, some regions in central and southern parts of Tehran are quite susceptible for ground motion amplification. In addition is some points in northern parts of the city, due to existence of loose deposits, the potential of amplification are again high.

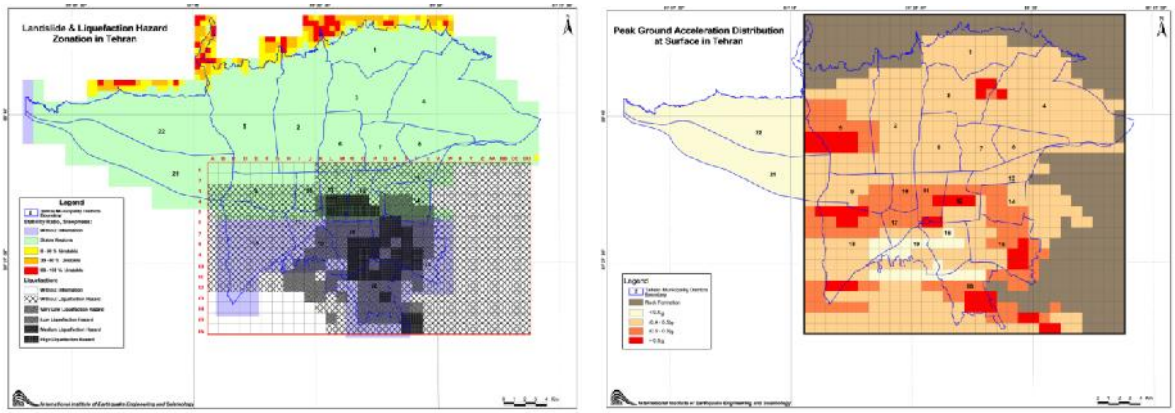

Figure 3. The areas prone of landslide and liquefaction (left) and Peak Ground Acceleration (PGA) distribution at surface (right) in Tehran (Jafari and Amini Hosseini, 2004)

The other geo-hazard that may be associated with earthquake in Tehran and has been considered in this study is land-subsidence due to collapse of Qanats (traditional underground irrigation channels). There are more than 300 lines of old Qanats in Tehran. Some of these channels are now active for draining water to low lands, while the locations of most of them are unknown. Even in static condition in some cases, due to rainfall, vibration or construction activities, some sinkholes may form above the hidden Qanats (figure 4).

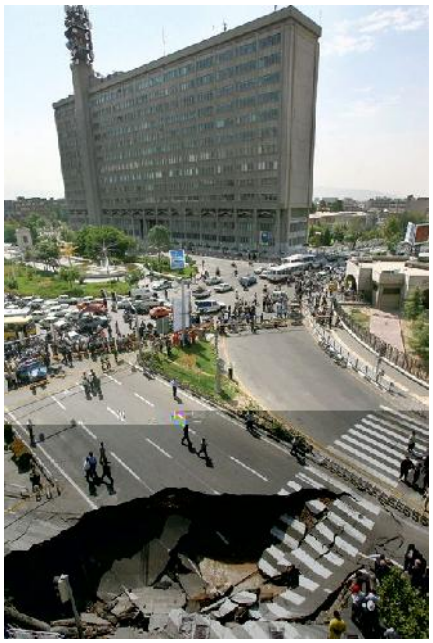

Figure 4. Land subsidence due to collapse of Qanat in Tehran

The experiences of Bam Earthquake of 2003 that occurred in south of Iran, depicted the importance of Qanats in earthquake. In that event, collapse of Qanats caused considerable damages to buildings and infrastructures, specially road networks and water supply of the Bam. Therefore it can be expected by collapse of Qanats during a potential earthquake in Tehran, the damages and casualties may increase to some extent.

GEO-HAZARD RISK MITIGATION POLICIES IN TEHRAN

Although up to now a uniform standard for geo-hazard risk mitigation in Tehran has not been prepared and approved by policy makers, but there are some activities to develop relevant criteria and guidelines. The most important document was prepared for Tehran Municipality by International Institute of Earthquake Engineering and Seismology (IIEES) to be considered in updating Tehran Master and Comprehensive Plans (Jafari and Amini Hosseini, 2004). In that project, some criteria and guidelines were developed and presented to Tehran Municipality to be considered in mitigation of geo-hazard in developing the city. These criteria cover a large verity of subjects from risk mitigation to emergency response activities. Some of the finding of that project can be summarized in the following parts:

A: Preparing seismic and geotechnical microzonation maps and damage estimation

- The microzonation studies in Tehran have been implemented in large scales (around 1:25000) to be used in urban planning. However, for critical sites the precision has to be increased to minimum 1:2000;
- It was tried to include all geological and geotechnical hazards (ground motion, fault rupture, landslides, liquefaction, site effects, subsidence, etc.) in preparing microzonation maps. However, in some areas conducting additional studies is essential;
- Assessment of the damages and casualties in different earthquake scenarios should be implemented using the local databases. In addition appropriate fragility and casualty functions should be prepared based on local conditions;
- Seismic microzonation maps should be used as a basis for preparing disaster management master plans in urban fabrics.

B: Risk mitigation in landslide prone areas: In order to reduce the impacts of landslides in Tehran, it is necessary to evaluate and control the trend of development towards these areas. For this purpose the following aspects should be considered:

- To identify landslide and rock-fall hazard zones and display the results on appropriate maps with proper scales;
- To provide and publish necessary information on landslides and its potential impacts and methods to reduce its effects to local residents, planners, managers, designers and decision makers;
- To prepare and approve necessary rules and regulation for controlling, preventing and restricting construction in hazard zones;
- To implement control, monitoring, early warning and remediation measures based on appropriate plans;
- To make training programs for improving relevant skills for evaluating and controlling hazards;
- To make necessary organization and allocate necessary budget for implementing above plans.

Accordingly the main guidelines and criteria for reducing the impacts of landslides in urban areas are as follows:

- To determine the risk of landslide and rock-fall in all existing slopes in the urban areas;
- To consider landslide risk in microzonation maps and urban developing plans (master and comprehensive plans) and to select safe areas for construction in or around the existing slopes;
- To control the landslide risk before issuing construction permits by the municipality and other relevant authorities;
- To prevent construction in hazardous zones without assessment the risk or implementing appropriate ground stabilization;
- To stabilize the slopes prone to rock-fall by using the appropriate measures such as rock-bolts, retaining walls, etc.;
- To adopt appropriate methods for construction of buildings and infrastructures on slopes based on the types of potential instabilities;
- To consider intentional weak points along the pipelines or other line elements linked to the buildings to reduce the overall damages to the networks in case of slope instability;
- To avoid construction of important structures such as school and hospitals on landslide prone zones;
- To equip the adjacent slopes to urban areas to monitoring and early warning systems;
- To prepared necessary tools and equipment in appropriate places and to train the local staffs of the rescue and relief agencies to make emergency response in case of landslide.

C: Development in liquefaction prone zones: The construction of important buildings and infrastructures on liquefiable ground should be restricted or prohibited if no remediation activities carried out in advance at the sites. However, there are many ways to reduce or eliminate the risk of liquefaction (including compaction, vibro- replacement, grouting, ground reinforcement, bridging, etc.), but most of them are time consuming and expensive. Therefore, before planning for ground improvement, the risk of liquefaction and its potential impacts on buildings and infrastructures should be evaluated and appropriate measures for controlling and preventing construction in hazard zones should be applied.

D: Development in Land Subsidence prone zones: Various methods for assessment the risk of land subsidence and improvement and stabilization of areas prone to this hazard are available. However before making any remediation plan, it is necessary to make geotechnical microzonation map for assessment the risk in different places. Then for the areas that are at risk to such hazards, ground improvement should be planned using different methods (bridging, vibration, dynamic compaction, grouting, filling the cavity with soil and rock, bridging, using underground piles, strengthening using lime, control of water flow, drainage, etc.). However, for urban development or renovation in hazard zones, the best solution is to avoid construction in or around underground spaces. It is also recommended to develop necessary codes and standards for regulating construction in hazard prone areas. Such regulations have been developed in the U.S. for construction in Karstic zones. It specifies the necessary details for construction to avoid triggering underground spaces that may result in making sinkholes.

TOWARDS RISK MITIGATION OF GEO-HAZARDS IN TEHRAN

In order to mitigate the impacts of geo-hazards in Tehran, the following measures can be implemented by Tehran Municipality and other relevant organizations. Such measures may be proposed to other countries facing similar challenges (Amini Hosseini et al., 2009).

1- Capacity building in preparing risk management plans: Preparing appropriate risk mitigation and management plans are necessary for reducing potential impacts of geo-hazards in Tehran. It is shown that the individual decisions and operations have not resulted in appropriate risk reduction by now. Therefore, all elements affecting geo-hazards should be considered to make an appropriate plan for risk mitigation and management. For this purpose, different aspects of geo-hazards associated with earthquakes and their potential impacts on built environment (buildings, infrastructures, etc.) should be studied and evaluated. Furthermore, the necessary laws and regulations as well as relevant guidelines should be prepared and organizational settings for reducing the impacts of geo-hazards need to be addressed based on local socio-economic conditions and appropriate measures for risk reduction should be proposed accordingly. The outcomes of such activities can be reflected into master, comprehensive and implementation plans to be considered in land-use planning by urban planners (Amini Hosseini and Ghayamghamian, 2012). Since geo-hazard risk management plans have many physical as well as socio-economic components and different organizations are involved in implementing the relevant responsibilities, it is necessary to assign an official institution to manage, organize and coordinate the defined activities. Normally disaster management organizations (or any similar institutions in any countries) can play this role, if supported by the local governments. However, they should be supported by providing the necessary resources and capacities to implement the relevant tasks appropriately.

2- Risk assessment and risk mapping: Assessment of the risks of landslides and other geological hazards and preparing hazard zonation maps, particularly in places that buildings and infrastructure are subjected to such instabilities, is essential when creating development plans and conducting remediation activities. In order to prepare hazard zonation maps, standard procedures and formats should be developed and utilized, so that the risk of different places can be compared. Furthermore, since the results of such assessments are recommended to be reflected into urban or regional development plans, the scales of the prepared maps in both cases need to be similar. Recently requirement to prepare microzonation maps according to standard scales has been enforced by relevant authorities in Iran, and now such maps have been prepared for Tehran and some other big cities in Iran. However, the information gained during microzonation has not yet been reflected into urban renovation or development plans.

3- Improvement of public awareness and professional knowledge: Different groups from ordinary people to officials should be provided with the necessary knowledge on the potential effects of geo-hazards, and the possible ways to reduce their impact. In fact, implementing risk reduction measures, such as prohibition of construction around unstable grounds and enforcing land-use plans in places exposed to geo-hazards, can be implemented more easily if appropriate information is provided to the communities and relevant authorities in advance. Public awareness is a function of know-how and understanding of the hazard situation from local to regional levels. Thus necessary information needs to be provided and translated into simple language to be used by different groups. Plans for dissemination of the information among the public should be also prepared. Besides of public awareness, the professional knowledge of relevant executive managers as well as civil engineers and urban planners on the risk of geo-hazards and ways to reduce and mitigate their impact should also be improved by organizing practical workshops and conducting applied research in universities and research centers.

4- Developing efficient plans for risk reduction: Different methods are available for ground remediation, stabilization and monitoring in the areas subjected to geological hazards. However, formulating such measures, considering their costs and complexity, needs precise risk assessment at the local level to be successful. Installation of monitoring and early warning systems in hazard zones, especially for those sites that are subjected to large scale instabilities or in the populated areas, also could be considered as a solution if overall stabilization is not feasible. Again, in the design of such systems, having an overall view on physical and socio-economic conditions of the target area is essential.

CONCLUSIONS

In this paper, some of the geological hazards that may be associated with earthquakes in Tehran have been introduced and some activities carried out for risk reduction in the city have been presented. Furthermore, by reviewing the experiences of some other countries in risk mitigation and management, a number of strategies have been presented. Based on the results of this study, the main parameters for formulating integrated geo-hazards risk mitigation and management plans in Tehran have be determined and classified into knowledge and information, institutional capacities and risk assessment and reduction groups.

In order to improve the existing conditions, it is necessary to determine priorities for strengthening each parameter by defining short, mid and long term programs. Based on the experiences from recent earthquakes in Iran, institutional capacities should be promoted in short term plans. This can be done by enforcing regulations, allocating budgets and strengthening institutional capacity. Risk reduction by using ground improvement is normally time consuming and more expensive and cannot be implemented prior to the risk assessment analysis. Thus, among the indicated parameters, those related to risk assessment as well as promoting knowledge and information should be carried out in short to mid-term programs prior to planning for remediation activities and ground improvement.

It should be also noted that for success in making such plans, it is necessary to centralize the coordination of all activities of relevant organizations involved in geo-hazard risk reduction and prevention. For this purpose, necessary organization that has sufficient power and authorities to take the responsibilities in these fields needs to be established. This organization may provide necessary funds and supervision on the activities of other related institutions to make the integrated plans for geohazards risk mitigation and management.

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