# REDUCING SEISMIC RISK IN TEHRAN USING URBAN DEVELOPMENT PLANS

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**ABSTRACT :**

Tehran is located in a seismic prone zone, surrounded by several active faults and experienced several destructive earthquakes in its history. Seismologists, based on the probabilistic and deterministic evaluations, believe that a strong earthquake would be expected in or around the city in near future. Furthermore, the vulnerability of the structures and urban areas in Tehran is quite considerable. Weak buildings, old urban structures, vulnerable lifelines, insufficient emergency infrastructures and roads, lack of evacuation places at several districts, etc. are some of the key parameters of earthquake vulnerability of the city. In order to improve the existing condition, a project carried out at International Institute of Earthquake Engineering and Seismology (IIEES) for Tehran Municipality for development guidelines and standards for city development and renovation based on the existing vulnerability and hazard level. For this purpose a general survey carried out in all aspects of risk reduction and management in Tehran. In this line at first the seismic and geotechnical hazards in Tehran have been evaluated and then the vulnerability of buildings, lifelines and urban structures has been studied. At the last stage the disaster management elements including emergency roads, rescue and relief stations, health and medical services and evacuation places have been considered. At the final step some guidelines and criteria were developed to be considered in Master and Comprehensive plans of Tehran to reduce the impacts of earthquake in the city based on socio-economic aspects. A summery about the developed criteria on urban tissues earthquake risk reduction will be presented and discussed in this paper and the results will be compared with some other existing criteria.

**KEYWORDS:** Risk Reduction, Tehran, Geotechnical Hazards

## 1. INTRODUCTION

Iran is a highly seismic prone country experienced several strong earthquakes in its history and most of the cities and towns are developed in earthquake prone zones. As an historical country, in most of the cities, some parts are covered by weak and old structures and urban tissues that are highly vulnerable to earthquakes. The Bam city which was demolished by the earthquake of 26 December 2003 is a typical sample of historical urban areas in Iran. Because of this event more than 26000 persons died and many more were injured and the effects of this event is still observable in the area. Destruction of most of the public buildings, hospitals, schools and several cultural heritage buildings including the Bam citadel with around 2500 years of history were some of the impacts of this event. Moreover, the rapid growth of urbanization and lack of strong regulations for urban development in the previous decades as well as immigration of low income residents of rural areas towards the bigger cities could be also considered as the other reasons on the development of vulnerable tissues in Iranian urban areas. The city of Tehran is also located in a seismic prone area of Iran and it is expected that a strong earthquake hit the city in the near future. Considering the high vulnerability of Tehran the impacts of such earthquake would be destructive.

In order to reduce the potential impacts of the earthquake in Tehran, some specific measures should be considered for area redevelopment. Retrofitting or reconstruction of structures, promotion of public participation in risk reduction, development necessary plans and program, etc. can be considered as the most important solutions for risk reduction. In line with these subjects, Tehran Municipality has considered the risk of earthquake in Tehran in updating the City Master Plan. One of the key issues in this study carried out by International Institute of Earthquake Engineering and Seismology, was related to the evaluation of vulnerability of old urban structures. In that study the vulnerability of urban areas were considered and necessary plans for risk reduction were developed. In this paper a summery about the most important criteria affecting in vulnerability of urban tissues will be presented and results of using these criteria for Tehran will be explained.

## 2. MAIN PARAMETERS OF VULNERABILITY OF URBAN FABRIC IN IRAN

Several earthquakes affected the urban and rural areas in Iran during the last decades that three of them caused considerable damages in urban areas including Tabas Earthquake of 1978 (Ms=7.4), Manjil Earthquake of 1990 (Ms=7.7) and Bam Earthquake of 2003 (Ms=6.5). In this research the effects of the last two earthquakes in old urban tissues have been evaluated, as there is no reliable data about the effects of the first event. In the evaluation of these events the main causes of casualties and vulnerability of urban tissues have been studied that the results can be listed as follows:

### *2.1. Weak buildings:*

This subject is the main cause of the vulnerability of urban areas during earthquakes. Especially in old urban tissues, most of the buildings suffer from lack of resistance to earthquake shaking as most of them were built decades ago without considering any seismic codes or criteria. In both cases of Bam (2003) and Manjil (1990) earthquakes, almost all of the weak buildings were collapsed or severely damaged by shaking. Figure (1) shows some of these damages.

(a) (b)

Figure 1 Damages to the weak buildings during (a): Manjil, 1990 and (b) Bam, 2003 Earthquakes

The most important reason for the buildings' destruction has been the structural vulnerability of them many of which made of adobe or violating the structural codes. Adobe, in the form of sun-dried bricks and clay or lime/clay mortar, has traditionally been the primary construction material in Iran. Presently, this type of construction still constitutes a notable portion of the buildings in the urban areas and a majority of the buildings in the rural areas. Performance of traditional adobe construction during numerous Iranian earthquakes has generally been poor. Low material strength, poor workmanship, lack of proper connections between building elements, and the excessive weight of the building because of thick walls and massive roofs, are a few of the shortcomings that contributed to the general weakness of these buildings under earthquake loads (Maheri et al, 2005). At the present time the vulnerability of the buildings is normally considered as one of the key parameters for evaluation of vulnerability of old urban areas.

### *2.2. Road network*

Most of the old urban areas suffer from narrow roads and alleys. This situation not only may cause difficulties for transportation in normal condition, but also would affect the emergency response activities after earthquakes due to blockage of existing roads by debris. Based on the current regulations in Iran for classification of vulnerable areas among old urban zone, the areas having narrow roads (less than 6 meters width) normally are considered as vulnerable urban tissues. Almost all the big and historical cities of Iran have some narrow roads and it is expected that most of them would be damaged or blocked by potential earthquakes. In Bam earthquake nearly all the narrow roads in historical parts of the city were completely blocked and it caused considerable delay in rescue and relief operation for several hours (figure 2).

Figure 2 Blockage of narrow roads by debris after Bam earthquake of 2003

### *2.3. Site effects*

This parameter that can be evaluated using the microzonation map has an important role for classification of vulnerability of urban tissues. Based on the geological subsurface condition there are the potential for amplification of earthquake strong motion in some parts. Site effects have caused difference in damage level in previous earthquakes in Iran. For example in Bam earthquake of 2003, different site effects caused amplification in some parts so the buildings constructed at these parts experienced more severe damages. Figure (3) depicts the site effect microzonation map of Bam in which the Bam area has been classified into 5 groups based on stiffness, thickness and frequency characteristics from rock like sites to medium stiff soil (Jafari et al, 2005). Based on this study highest value of damage were concentrated in sites with stiff shallow and medium depth soils which caused considerable amplification in high frequency ranges.

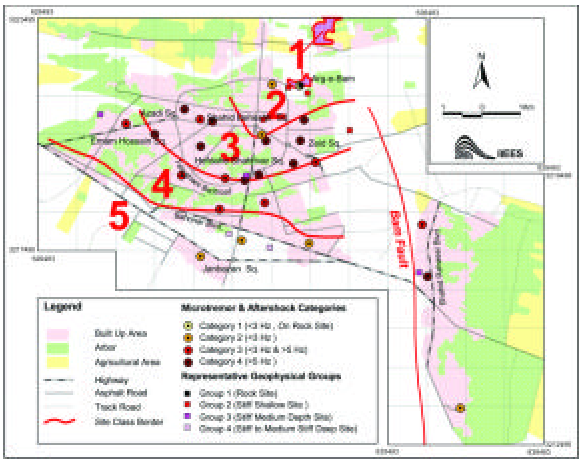


Figure 3 Site effects microzonation map of Bam

### *2.4. Geological and industrial hazards*

Geological hazards such as liquefaction, landslide or rock fall, land subsidence, fault rupture that can be induced or triggered by earthquake motions may increase the vulnerability level of urban tissues. During the Manjil earthquake of 1990, a big landslide covered one part of the city of Manjil, called Fatalak, and almost 100 persons were buried under the debris. In addition during Bam earthquake of 2003, land subsidence due to collapse of Qanats (underground irrigation units) caused severe damages to several buildings and lifelines (Amini Hosseini et al, 2004) as shown in figure (4). These examples shows that the urban tissues located in geological hazard zones normally will experience more severe damages in earthquakes so the vulnerability of these sites are much higher than the similar tissues located in other areas.

Figure 4 Sinkholes caused severe damages to the buildings in Bam Earthquake

Besides of the geological hazards, the vulnerability of urban areas may be also increased by existence of the hazardous facilities such as tank farm, petrol or gas stations, chemical material storages, etc. Damages to these facilities during earthquakes may cause explosion, fire or even diffusion of poisonous gases in the areas that may affect on citizen lives. Considering the placement of these facilities in different parts of a city, the nearby areas could be considered as more vulnerable sites against earthquakes and some measures should be considered for redevelopment of these areas.

### *2.5. Emergency response facilities*

Immediately after an earthquake and during the first 72 hours, that normally called “golden hours” the emergency response activities can save a lot of lives of the victims trapped under the debris or rescued by the peoples or experts. Search, rescue and relief could be considered as the most important emergency response activities during these golden hours, so the placement of the related facilities (fire and rescue stations, hospitals or medical centers, etc.) near the affected areas could improve the access to the victims and providing necessary responses and cares.

The urban tissues that have such facilities normally could be considered more safe sites against earthquakes, so this parameter could be considered as a parameter for redevelopment planning of urban areas in earthquake prone zones. In Bam earthquake of 2003 due to huge number of casualties and damages to the existing hospitals, several injured persons were transferred to adjacent cities that considerable numbers of them were died in the way because of lack of sufficient emergency medical cares. Moreover damages on fire stations, delay of dispatching the rescue teams to the areas and lack of necessary equipment for rescue activities caused extra problems for rescue activities during the first 24 hours (figure 5).

(a) (b)

Figure 5 Damages to Imam Hospital (a) and a fire station (b) during Bam earthquake of 2003 caused delay in rescue and relief activities

### *2.6. Evacuation places*

Evacuation is an important issue for reducing the casualty of earthquakes. It could be considered before an earthquake (by feeling some foreshocks or using modern early warning system) or after an earthquake (when there is the risk of fire or collapse of building by aftershocks). In both cases if the people could not be properly evacuated to safe evacuation places through proper evacuation routes, more serious human casualties will be expected. So allocating of the safe evacuation places before an earthquake can reduce the vulnerability level of urban tissues in risk reduction and can be considered for classification of urban tissues in earthquake prone areas. In the previous earthquakes in Iran, the lack of sufficient evacuation places to be used in different weather condition caused serious difficulties especially in Bam case. In that event although the people felt some foreshocks, but due to cold weather condition they could not stay outside of their houses. In this case even after the earthquake lack of proper places for evacuation, caused several peoples be accommodated into tents in not proper places (figure 6).

Figure 6 One of the evacuation places prepared after Bam earthquake of 2003

### *2.7. Other parameters*

It seems that besides of the above indicated items, some other parameters should be also considered when evaluating the vulnerability of urban tissues against earthquakes. Population density, percentages of weak population, lifeline vulnerability especially water supply network, open space proportions around the buildings, as well as socio economic conditions of the residents are some of these parameters that due to lack of necessary evidences and documents in previous earthquake of Iran, their impacts could not be evaluated in this paper.

## 3. EVALUATION THE VULNERABILITY OF URBAN FABRICS IN TEHRAN

The city of Tehran, the Capital of Iran, is located in a seismic prone area in Southern parts of Alborz Mountain ranges and has surrounded by several active faults and experienced several destructive earthquakes in its history Seismologists based on probabilistic and deterministic analysis predict that a strong earthquake would be expected in the city or around it in near future. On the other hand the analysis of vulnerabilities of structures and infrastructures in Tehran depicts that in case of a big earthquake, considerable damages and casualties could be expected in the area especially in the old parts. In fact the city of Tehran has been developed rapidly during the last few decades (table 1). About 200 years ago Tehran was a small village in the North-west of Ray (previously called "RAGA"); an important historical city that was located in "Silk Road". Due to rapid urbanization and lack of strong rules and regulations in some periods of the time, the developments in Tehran in some areas were not based on engineering plans and standards. So the vulnerability of Tehran at the present time is considerably high.

Table 1 Population and Urban Area growth in Tehran since 1891 to 2000 (Amini Hosseini et al, 2007)

| Year | Urban Area ($Km^2$) | Population |
|---|---|---|
| 1891 | - | 160.000 |
| 1922 | 24 | 210.000 |
| 1932 | 30 | 310.000 |
| 1937 | 32 | 500.000 |
| 1939 | 44 | 540.000 |
| 1941 | 65 | 700.000 |
| 1956 | 100 | 1.512.000 |
| 1966 | 181 | 2.719.000 |
| 1980 | 370 | 5.443.000 |
| 1986 | 567 | 6.042.000 |
| 1991 | 588 | 6.475.000 |
| 1996 | 720 | 6.758.000 |
| 2000 | 720 | 6.960.000 |

During the recent years, considerable activities were carried out to reduce the impacts of the potential earthquake in Tehran. One of these activities is related to the retrofitting of structures and renovation of old and vulnerable parts of the city that would be discussed in the following parts.

### *3.1. The existing plan for identification vulnerable urban tissues against earthquake in Tehran*

Tehran Municipality based on the regulation of The High Commission of Urbanism and Architecture of Iran, belongs to the Ministry of Housing of Iran, prepared some plans and regulations for prioritizing the urban redevelopment. Based on these regulations, three parameters should be considered as the main criteria for identification and categorization the vulnerable urban tissues including vulnerability of buildings, size of houses and width of existing road network in each block. Based on these regulations an urban tissue will be considered vulnerable if meet one or some of these criteria as explained in the following parts.

#### *3.1.1. Evaluation of vulnerable blocks based on the distribution of weak buildings*

In order to use this criterion, the buildings have been categorized into three groups of low to high vulnerability. The highly vulnerable buildings include adobe structures, masonry building without skeleton and so on. In each block the areas of highly vulnerable blocks have been evaluated and if the summation of them is more than 50% of the areas of all buildings located in the blocks, then the block considered as highly vulnerable block.

### *3.1.2. Size of houses inside the blocks*

Based on this criteria, the size of each house in the blocks, including the building floor areas and its around open spaces in individual house, have been evaluated and then in each block the number of houses having less than 100 $m^2$ areas have been evaluated as vulnerable houses. If the numbers of these houses are more than 50% of total number of houses in each block, then the block considered as vulnerable. Of course the size of individual houses could not directly shows the vulnerability, but indirectly could be considered as a measure showing the economic condition of the residents and population density at risk, that are important in earthquake risk evaluation.

### *3.1.3. Width of existing road network into blocks*

This criterion is an important parameter showing the access to the blocks and the risk of blockage after an earthquake. Based on this parameter, length of the roads having less than 6 meters width should be measured and compared with the total length of the roads inside the blocks. If the ratio is higher than 50%, then the block considered as vulnerable. Based on these criteria the city of Tehran has been categorized into 7 groups including areas having only one of the criteria 1 to 3 or combination of them. The worst cases that include areas having all three conditions are shown in table (2).

Table 2 The most vulnerable areas in Tehran having all three criteria based on the existing regulations

| District number | Most Vulnerable Areas ($m^2$) | District number | Most Vulnerable Areas ($m^2$) |
|---|---|---|---|
| 1 | 25,000 | 12 | 39,667 |
| 2 | 11,173 | 13 | 64,075 |
| 3 | 7,140 | 14 | 340,734 |
| 4 | 52,674 | 15 | 1,056,260 |
| 5 | 2,690 | 16 | 316,327 |
| 6 | 10,093 | 17 | 805, 615 |
| 7 | 52,976 | 18 | 104,544 |
| 8 | 368,302 | 19 | 2,021 |
| 9 | 392,216 | 20 | 99,588 |
| 10 | 797,678 | 21 | - |
| 11 | 53,479 | 22 | - |

### *3.2. Classification of earthquake vulnerable areas in Tehran*

Although the above indicated criteria provide a better picture of the situation of urban fabrics in Tehran to a disaster, but as mentioned before, those parameters are not sufficient for identification vulnerable urban areas in the view points of earthquake. For considering earthquake effects in area redevelopment, a project carried out in Tehran Disaster Management Organization (TDMO) with co-operation with Japan International Cooperation Agency (JICA) to develop new criteria for identification and prioritized of vulnerable urban fabrics in Tehran. In this study the vulnerability of urban tissues in Tehran has been evaluated using the following parameters:

A- Building Damages: In this study the building vulnerability has been evaluated based on the earthquake scenarios. Among the main active faults surrounding Tehran, Ray Fault and North Tehran Fault (NTF) could generate the strongest earthquakes impacts; having different PGA (Peak Ground Acceleration) in southern and northern micro zones. In this study the maximum amounts of PGA have been considered for each micro zone, so for the northern parts the estimated PGA's of NTF fault have been applied while for the southern and central zones, the PGA's generated by Ray Fault were considered.

B- Evacuation: Proper evacuation plans would reduce the casualties of earthquake that may cause by building collapse or secondary disasters such as fire. Parameters such as availability of evacuation places, disaster weak population ratio (handicapped persons and those having age more than 65/less than 5 years), road blockage ratio (ratio of the roads blocked by debris due to the collapse of buildings), evacuee densities on evacuation routes, and so on were considered in this item for categorization of vulnerable urban tissues.

C- Secondary disasters: After an earthquake, secondary disasters may occur by hazardous, flammable and explosive materials that would increase human casualties and damages. In this study the location and effects of hazardous facilities (chemical storages, chemical factories, …), and flammable or explosive materials (gas station, high pressure gas filling and refilling stations, natural gas pipelines and facilities, etc) as well as electricity network were considered to identify vulnerable urban areas.

For analysis the results, each of the above indicated parameters were classified into 5 groups showing the existing conditions and then each component have been weighted to analyze the integrated vulnerability of Tehran. Based on this analysis, urban tissues of Tehran were classified at sub-district levels (Nahiye) into three categories, as follows:

- Priority Improvement Area which are most vulnerable areas and need urgent actions with emphasis on area-based re-development;
- Improvement Area which means improvement in some parts having high risk is necessary. These parts expected to be seriously damaged by earthquake;
- Built-up Area that is some places that does not in great danger and need individual improvement of buildings or infrastructures.

## 4. CONCLUSION

The results of the studies presented briefly in this paper show the importance of considering several parameters for planning the renovation of urban areas in seismic prone zones. Based on the indicated items, it is obvious that the priority for improvement of the city tissues could be different when considering the earthquake related parameters. This shows the necessity for improvement of developing plans based on the hazard level and existing physical and social aspect.

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