A Survey on the Parameters Affecting the Vulnerability of Urban Fabrics to Earthquake in Tehran

K. Amini Hosseini & S. Hosseinioon
Disaster Risk Management Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran

15 WCEE
LISBOA 2012

SUMMARY:
In this paper for evaluating the impacts of seismic hazards to urban areas, a multi-dimensional survey was carried out to indicate the most important parameters affecting the vulnerability of the urban fabrics in earthquake prone zones using the experiences of recent earthquakes in Iran. These parameters then were categorized into different groups related to the urban built environment including seismic hazards, geological hazards and site effects, physical vulnerability, socio-economic conditions and disaster management capacity. By considering these items, the vulnerability of urban areas in some parts of Tehran were evaluated and compared with the plans that have been prepared based on limited physical parameters for prioritizing and retrofitting the old urban areas in the city.

Keywords: Urban Fabrics, Earthquake, Tehran, Vulnerability

1. INTRODUCTION

Iran is a highly seismic prone country which experienced several strong earthquakes in its history and most of its cities and towns are developed in earthquake prone zones (Amberaseys and Melville, 1982). As a historical country, in most of the cities, some parts are covered by weak and old structures and urban fabrics that are highly vulnerable to earthquakes. The city Bam which was demolished by the earthquake of 26 December 2003 is a typical sample of historical urban areas in Iran. Because of that event more than 26,000 persons died and many more were injured and the negative effects of the 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 Bam Earthquake (Movahedi, 2005). 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 can be considered as the main reasons for the growth of vulnerable fabrics in Iranian urban areas. Tehran, the capital of Iran, is also located in a high seismic hazard prone zone that is at high risk of earthquake (CEST and JICA, 2000). The city is enlarged rapidly and irregularly during the last 100 years, towards the active faults and unstable slopes as shown in Fig. 1 (Amini Hosseini, and Jafari, 2007).

Figure 1: The trend of growth of city of Tehran towards the main faults

The most vulnerable fabrics in Tehran are old parts, located mostly between narrow streets in the areas with insufficient emergency response facilities. In order to reduce the vulnerability of these fabrics, Tehran City Council encourages the citizens for rehabilitation of the existing old buildings, and considers some advantages for this purpose (including dedicated fund for reconstruction, financial subsidization system, proper taxation system, etc). The results of this policy on improvement of individual units were considerable and up to now several owners have used the provided facilities for reconstruction of their own buildings. Of course, this policy did not have considerable effects on reducing the seismic risk in whole areas, as several means of earthquake risk reduction that are out of the scope of private owners, were not considered properly in such rehabilitation plans. In fact, for reducing the seismic risk in urban fabrics, physical and social parameters related to vulnerability of whole area should be considered and integrated in a logical manner to provide the best methods for urban disaster risk reduction. These parameters will be discussed in this paper.

2. PARAMETERS AFFECTING THE VULNERABILITY OF URBAN FABRICS TO EARTHQUAKE

Different parameters introduced worldwide to assess the vulnerability of urban fabric in earthquake prone zones and prioritizing them for improvement (Davidson, 1997, Davidson and Shah, 1997, and Carreno, Cardona, and Barbat, 2007). However, in this paper based on the local conditions in Tehran some parameters have been selected and weighted to evaluated the vulnerability of the city to potential earthquake. The most important parameters used in this research are introduced in the following parts.

2.1. Vulnerability of Buildings

This subject is the main cause of the vulnerability of urban areas during earthquakes. Especially in old urban fabrics, 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 Iran Bam (2003) and Manjil (1990) Earthquakes, almost all of the weak buildings were collapsed or severely damaged by shaking. In Iran and based on the regulation of High Council of Urban Development and Architecture (1999), the buildings can be categorized into three groups from low to high vulnerability considering the type, age and material of the structures. In planning for rehabilitation, the first priority is related to the most vulnerable buildings; including mud brick structures, masonry building and buildings with weak structures. In each block, the areas of such buildings will be evaluated and if the summation of them is more than 50% of the areas of all buildings located in the block, the block is considered as high vulnerable block (Nateghi, 2001).

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 conditions, but also would affect the emergency response activities after an earthquake due to blockage of existing roads by debris (Amini Hosseini and Hosseini, 2007). Based on the current regulations in Iran for recognition and classification of vulnerable areas to disasters, especially earthquakes, the areas having narrow roads (less than 6 meters width) are normally considered as vulnerable urban fabrics. Almost all the big and historical cities of Iran have a percentage of 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 operations.

2.3. Geo-hazards and Site Effects

Geological hazards such as liquefaction, landslide or rock fall, land subsidence and fault rupture which can be induced or triggered by earthquake motions may increase the vulnerability of urban fabrics. For instance, the 1990 Manjil earthquake triggered a big landslide that covered Fatalak Village, buried almost 100 people under the debris. In addition during the 2003 Bam earthquake, land subsidence due to collapse of Qanats (underground irrigation tunnels) caused severe damages to buildings and lifeline network (Amini Hosseini et al, 2004). These examples shows that the urban fabrics located in geological hazard prone zones normally will experience more severe damages in earthquakes so the vulnerability of these sites are much higher than the similar fabrics located in other areas.

Besides of geo-hazards, site effects may also increase the vulnerability of urban fabrics. This parameter can be evaluated using the microzonation maps. Based on the geological subsurface conditions; there is the potential of 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 such parts experienced more severe damages.

2.4. Industrial Hazards

The vulnerability of urban areas may be also increase by presence of the hazardous facilities such as tank farms, 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 vulnerable sites and measures should be considered for redevelopment and safety of these areas.

2.5. Emergency Response Facilities

Immediately after an earthquake and during the first 72 hours, which are called the "golden hours", the emergency response activities can save the lives of many victims trapped under the debris, or rescued by the people/experts. Search, rescue and relief activities can 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 fabrics that have such facilities normally could be considered safer sites against earthquakes, so this parameter should be considered as a parameter for redevelopment planning of urban areas in earthquake prone zones (Jafari and Amini Hosseini, 2005). In the Bam Earthquake of 2003, due to huge number of casualties and damages to the existing hospitals, several injured persons were transferred to adjacent cities and a considerable number of them died on the way because of lack of sufficient emergency medical care facilities or centers. Moreover, damages to fire and RCS stations caused delay in dispatching the rescue teams to the affected areas and lack of necessary equipment for rescue activities caused extra problems for rescue activities during the first 24 hours.

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 systems) or after an earthquake in case of secondary dangers (when there is the risk of fire or collapse of building by aftershocks). In both cases if people can not be properly evacuated to safe evacuation places through proper evacuation routes, serious human casualties is expected. So allocating the safe evacuation places before an earthquake can reduce the vulnerability level of urban fabrics in risk reduction. In the previous earthquakes of Iran, the lack of sufficient evacuation places considering different weather conditions (such as severe cold or heat) caused serious difficulties especially in Bam case. In that event although the people felt some foreshocks during the night, but due to cold weather conditions they could not stay outside of their houses for long time and returned home before the main shock. In that case, lack of evacuation sites caused several difficulties in accommodating people in proper places to reduce the death toll.

2.7. Other Parameters

It seems that in addition to items indicated above, some other parameters should also be considered when evaluating the vulnerability of urban fabrics against earthquakes. Population density, percentage 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 which their impacts could not be evaluated in this paper due to lack of necessary evidences and documents in previous earthquakes of Iran.

3. ASSESMENT OF THE VULNERABILITY OF URBAN FABRIC IN THE PILOT AREA

In order to assess the effectiveness of the proposed parameters for assessment the vulnerability of urban fabrics to potential earthquake, a part of District 17 of Tehran has been selected as pilot area. The selected area includes 13 census zones and 149 blocks with 38130 residents having a population density of 803 people per hectares. Fig. 2 depicts the location of the pilot area in Tehran among District 17.

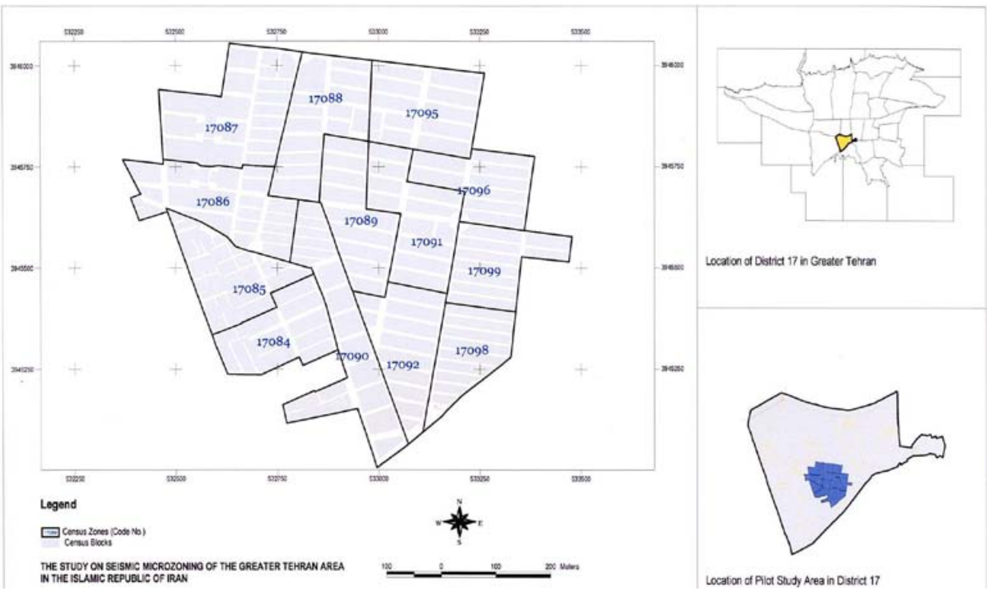

Figure 2: The location of the pilot site in Tehran (CEST and JICA, 2000)

Based on the existing data most of the buildings constructed in this zone are unstable to earthquake as they are mainly masonry buildings that built before the enforcement of Iranian Seismic Code (Standard 2800) as shown in Fig. 3. Furthermore most of the streets and alleys in the areas are narrow roads that could be blocked by collapse of adjacent buildings after potential earthquake. In addition many blind alleys can be found in the area as well. In Fig. 4 the blockage index of the area is shown.

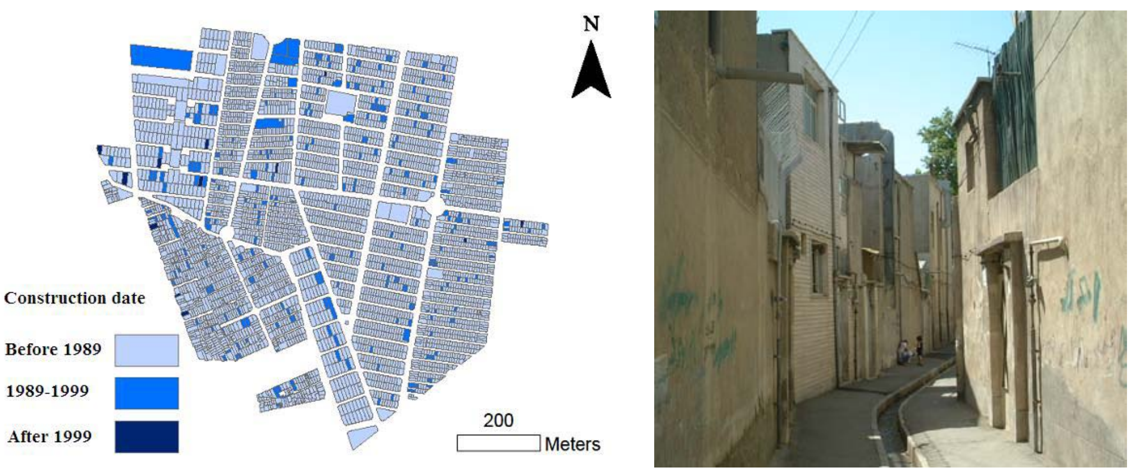

Figure 3: Distribution of weak buildings and samples of masonry building in narrow streets at the pilot area

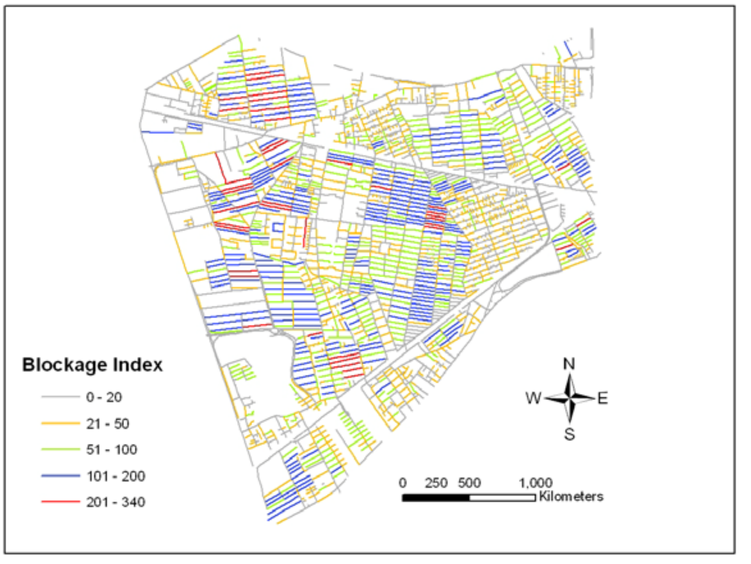

Figure 4: Blockage Index of roads at the pilot area.

According to the geological maps and geotechnical data, the risk of landslide and liquefaction in the area is not very high; however, due to existing Qanats (Old underground irrigation channels) the risk of land subsidence in some parts is considerable. In addition hazardous facilities (such as gas stations) can be addressed in some parts of the region that has been considered in this research. Distribution of PGA in the area is also different as shown in Fig. 5.

Figure 5: Distribution of PGA at the pilot area, Ray Fault model

The emergency response bases in the pilot area are very limited, but there are some facilities that can be used for improving emergency response capacities including public schools (elementary to high schools), clinics, doctors' offices, open spaces and parks. The location and distribution of the relevant sites are shown in Fig. 6.

Other information that were used for evaluation of vulnerability of the selected site to potential earthquakes are population density, density of weak population to earthquake, number of vulnerable buildings per blocks, areas of the blocks, etc. These parameters and the weighing factors for their evaluation are summarized in Table 1.

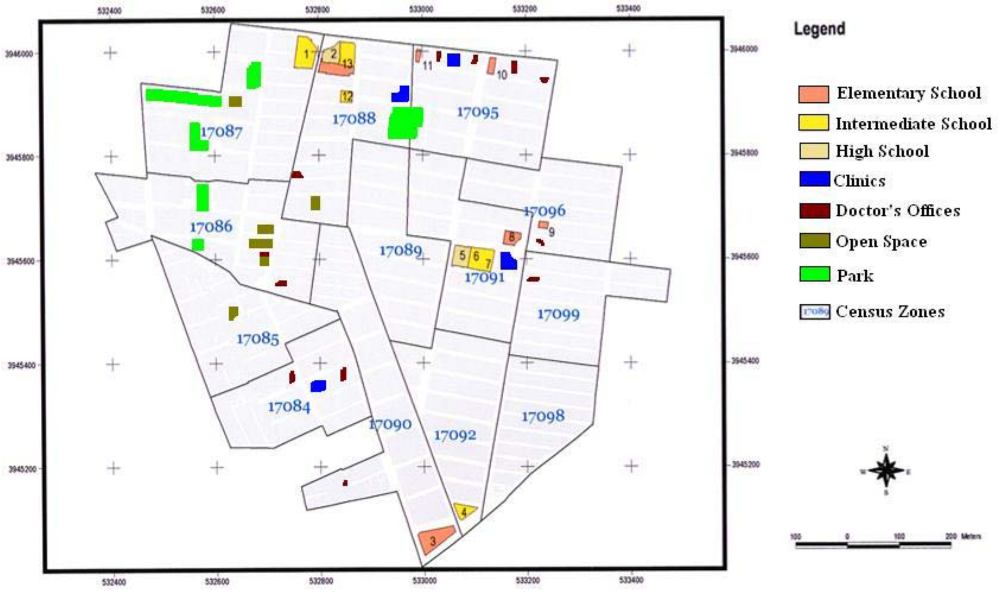

Figure 6: Potential places for emergency response at the pilot area

Table 1: The Parameters Used for the Evaluation of Vulnerability of the Pilot Area and the Weighting Factors

Parameters	Ranges	Value	Weighing factor	Parameters	Ranges	Value	Weighing factor
Number of vulnerable buildings	> 60	5	3	Ratio of roads wider than 12 m to all roads	0-10	5	2
	46-60	4			11-20	4	
	31-45	3			21-30	3	
	16-30	2			31-40	2	
	0-15	1			> 40	1	
Number of vulnerable buildings to block area	> 120	5	3	PGA (Gal)	> 500	2	3
	91-120	4			< 500	1	
	61-90	3		Risk reducing land use	Yes	0	1
	31-60	2			No	2	
	0-30	1		Risk increasing land use	Yes	2	1
Population Density	> 1000	5	2		No	0	
	751-1000	4		Population	> 400	5	2
	501-750	3			301-400	4	
	251-500	2			201-300	3	
	0-250	1			101-200	2	
Weak population Density	> 100	5	2		0-100	1	
	76-100	4					
	51-75	3					
	26-50	2					
	0-25	1					

4. CONCLUSION AND RESULTS

The vulnerability of each block and the priorities for improvement of the urban fabrics has been determined based on the Integrated Vulnerability Index that is introduced in this research and calculated using the following equation:

$$V_i=\sum F_i P_k \quad (1)$$

In this relation, V_i is the Integrated Vulnerability Index, F_j is the weighting factor and P_k is the value of the selected parameter which is determined based on the table 1. Using the above relation the most vulnerable blocks that need immediate attention for risk reduction measures can be determined. The results are shown in Figure 7.

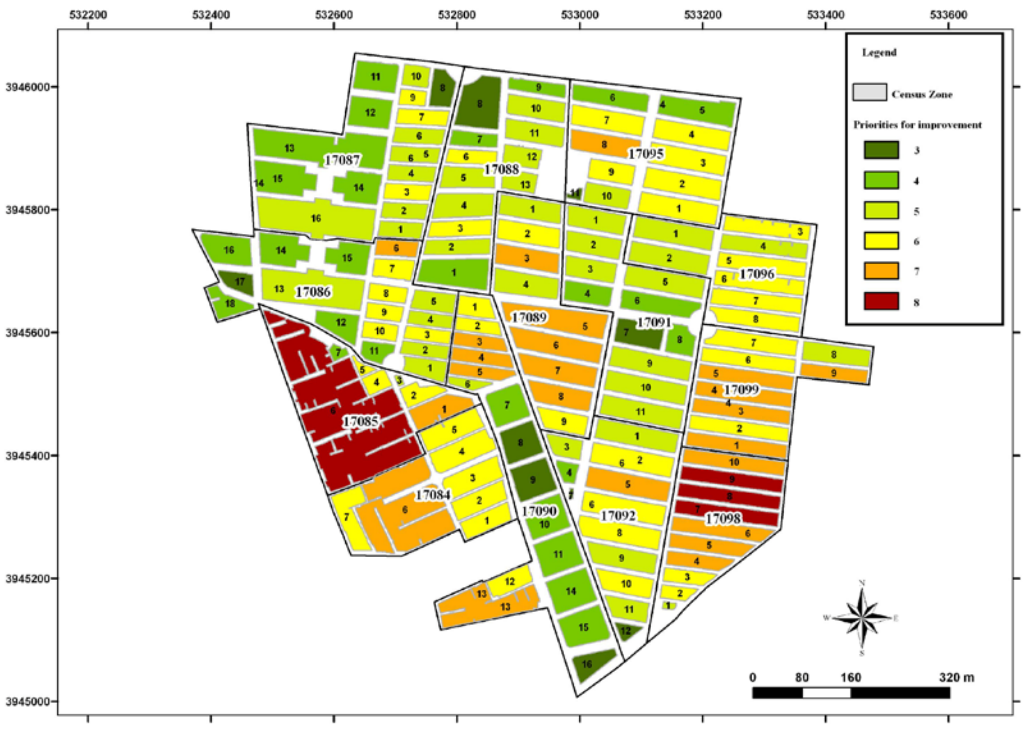

Figure 7: Priorities for improvement at the pilot area, the red zones are the most vulnerable blocks

It should be considered that by applying traditional methods of vulnerability assessment based on few physical parameters, all blocks in this pilot area were considered as vulnerable blocks need to be renovated. Therefore, it can be concluded that the introduced method can be applied more practically for city manager in allocating limited budget normally exist for such plans. This method can be also used by disaster management authorities for improving the necessary facilities among the urban fabrics to reduce the overall risk.

REFERENCES

Amberaseys, N. N. and Melville, C. P. (1982) A History of Persian Earthquakes, Cambridge University Press, London;

Amini Hosseini, K. and Hosseini, M. (2007) Evaluation of old urban structures and emergency road networks vulnerabilities to a potential earthquake in Tehran, *5th International Conference of Seismology and Earthquake Engineering (SEE5)*, Tehran, Iran;

Amini Hosseini, K. and Jafari, M. K. (2007) Development guidelines for disaster risk management, *5th International Conference of Seismology and Earthquake Engineering (SEE5)*, Tehran, Iran;

Amini Hosseini, K., Mahdavifar, M. R. and Keshavarz, M. (2004) Geotechnical instabilities occurred during the Bam Earthquake of 26 Dec. 2003, *Journal of Seismology and Earthquake Engineering* **5:4**, 57-69;

Carreno, M. L., Cardona, O. M. and Barbat, A. H. (2007) Urban seismic risk evaluation: a holistic approach, *Natural Hazards* **40:1**, 137-172;

Center for Earthquake Studies of Tehran (CEST) and Japan International Cooperation Agency (JICA), (2000), The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran, Main Report, Tehran, Iran;

Davidson, R. (1997) An Urban Earthquake Disaster Risk Index, The John A. Blume Earthquake Engineering Center, Report no. 121, Stanford, California;

Davidson, R. and Shah, H. (1997) Risk Classification of Megacities, *First International Workshop on Earthquakes and Mega-citie*s, Frankfurt, Germany;

High Council of Urban development and Architecture of Iran (1999) Approved criteria for identifying the obliterated urban fabric in Iran, Ministry of Housing and Architecture, Tehran, Iran (In Farsi);

Jafari, M. K. and Amini Hosseini, K. (2005) Earthquake Master Plan of Tehran, Final Report, International Institute of Earthquake Engineering and Seismology, Tehran, Iran;

Movahedi, R. (2005) ‘Search, rescue and care of injured following the 2003 Bam, Iran earthquake’. Earthquake Spectra **21:S1**, S475–S486;

Nateghi, F. A. (2001) Earthquake scenario for mega-city of Tehran, *Disaster Prevention and Management* **10: 2**, 95-100.