Recognition of Vulnerable Urban Fabrics in Earthquake Zones: A Case Study of the Tehran Metropolitan Area

K. Amini Hosseini [1], M. Hosseini [2], M.K. Jafari [3] and S. Hosseinioon [4]

1. Assistant Professor, Risk Management Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, I.R. Iran, email: kamini@iiees.ac.ir
2. Assistant Professor, Earthquake Engineering, Islamic Azad University (South Branch), and President of Tehran Disaster Mitigation and Management Organization, Tehran, I.R. Iran
3. Professor, Geotechnical Engineering Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, I.R.Iran
4. Research Assistant, Tehran Disaster Mitigation and Management Organization, Tehran, I.R. Iran

ABSTRACT

Vulnerability of urban fabrics to potential earthquakes is related to several parameters including seismic and geological hazards level, site effects, physical vulnerability, social and economical conditions and disaster management/ emergency response capacity. In order to evaluate the impacts of these parameters and estimate the integrated vulnerability at each urban fabric, it is essential to study their effects separately and then compile them by using appropriate methods and weighting factors. In this paper the seismic vulnerability of Tehran will be evaluated by considering some of the above-mentioned parameters and then the results will be compared with the existing plans and programs for rehabilitation of the old urban fabrics in Tehran prepared based on the laws and regulations of Ministry of Housing and Urban Development of Iran. The results show that the plans which are prepared merely based on physical vulnerability, can not properly identify the priorities for rehabilitation of urban fabrics in seismic prone zones and it is necessary to consider the impacts of earthquake related parameters as well as socio-economic conditions for improvement of vulnerable areas.

Keywords:
Urban fabrics;
Earthquake zones;
Vulnerability criteria,
Rehabilitation;
Tehran

1. Introduction

Iran's vulnerability to earthquakes is a living fact throughout the history which has caused the destruction of many human habitats in this country [1]. As a historical country, in most of the cities of Iran, some parts are covered by adobe, masonry or traditional structures and urban fabrics that are highly vulnerable to earthquakes. The city of Bam that was demolished by the earthquake of 26 December 2003 is a typical example of vulnerability of Iranian historic cities to strong earthquakes [2]. During that event around 85% of the buildings in the city of Bam, including private and public structures and cultural heritage buildings such as Bam Citadel with around 2500 years history, have been heavily damaged or destructed and caused more than 26,000 deaths [3].

Besides the vulnerability of structures in Iran, the rapid growth of urbanization, lack of strong regulations for urban development in some period of the time and immigration of low income residents of rural areas towards the cities are other causes of increasing vulnerable fabrics in most urban areas of Iran during their history.

Tehran, the capital of Islamic Republic of Iran, is also in high danger of earthquakes. As shown in Figure (1), the city has been surrounded by several active faults and has experienced many strong earthquakes through out history. Seismologists believe that a strong earthquake could be expected in Tehran in near future. The researches also show considerable vulnerability of Tehran to potential strong earthquakes as explained in [4] and [5].

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, the Tehran City Council encourages the citizens for rehabilitation of the existing old buildings, and considers some advantages for this purpose, including

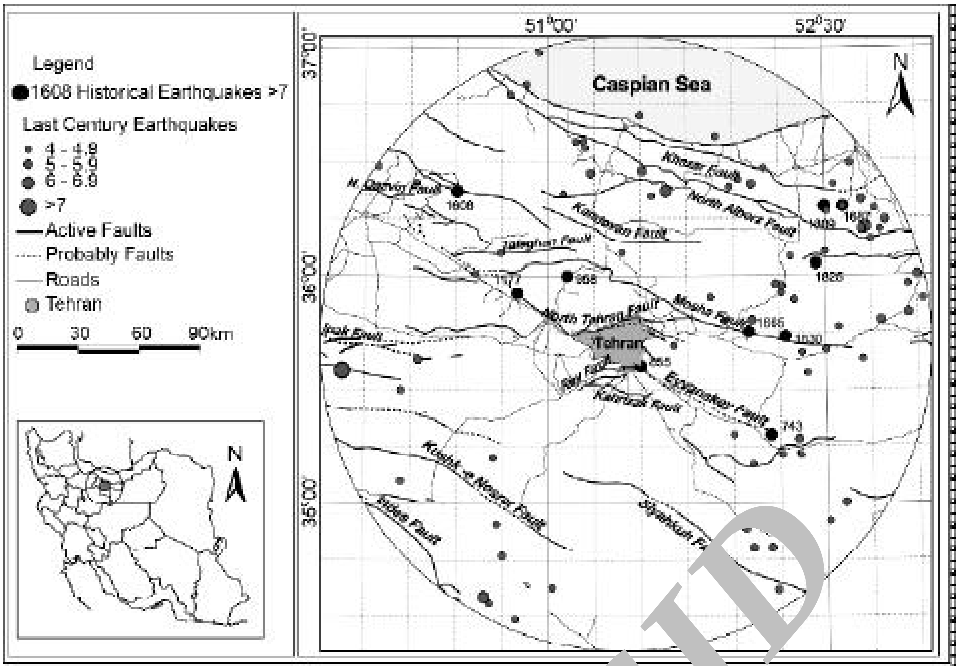

Figure 1. Main faults around Tehran and the location of historical and recent earthquakes around the city in 150 km radius [6].

dedicated fund for reconstruction, financial subsidization system, proper loans, and taxation system, etc. The results of this policy on the 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 it 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 the whole area should be considered and integrated in a logical manner to provide the best methods for rehabilitation.

In this paper two methods for evaluation of vulnerable urban fabrics will be introduced and applied for Tehran accordingly. The first one is adopted using the existing physical criteria for identification of old urban structures that have been approved by the Ministry of Housing and Urban Development of Iran, and the second method is developed on the basis of earthquake related physical and social parameters. Then the results of application of these two methods for Tehran will be presented and compared. It should be indicated that the impacts of some of the introduced parameters may not be considerable for the case of Tehran, but as these methodology may be used in other cities as well, therefore, they are also presented in this paper.

2. Existing Criteria for Recognition of Vulnerable Urban Fabrics in Iran

Different criteria exist worldwide to study the vulnerability of urban fabric and prioritizing them for improvement in earthquake zones. Immediately after the 1989 earthquake, the city of San Francisco organized a taskforce and commissioned a series of studies of the options to retrofit vulnerable fabrics (including some 2,000 privately owned unreinforced masonry buildings) in the city [7]. Two major studies were released by the taskforce, one analyzing structural and seismic issues [8], and another analyzing socioeconomic and land use considerations [9]. The analyses are distinguished by two factors: First, they provide detailed estimates of the costs of various retrofit alternatives that is estimates which vary with the type of structure as well as the level of investment. Second, the analyses summarize extensive simulation evidence on the likely consequences of earthquakes in San Francisco, including estimates of loss of life, injury, and property loss. The availability of these data permits a detailed analysis of the retrofit options and the benefits of investment in structural changes to these buildings.

In Japan, the selection of vulnerable fabric are based on the structural and infrastructural situation, relation between sites and roads, land use zoning regulation, building height-bulk-shape control, and restrictions in fire protection zones [10]. Considering these parameters, the vulnerable fabrics can be selected and necessary measures for rehabilitation can be implemented.

In Turkey and specially after Izmit earthquake of August 17^{th}, 1999, the land use planning in conjunction with building codes, were considered more seriously. Moreover earthquake related parameters such as primary and secondary effects and impacts, including ground-shaking, fault rupture, liquefaction, rock or landslides, fire, etc, and the potential destruction of social or economic cohesion within an affected community were considered in categorizing vulnerable fabrics. In addition to rehabilitation plans and based on the existing hazards in different parts, some land use regulations were developed in order to reduce the impacts of potential earthquakes [11]. In this line, some criteria were considered to evaluate the vulnerability of individual structures and their effects on urban fabrics.

In Iran, the High Council of Urban Development and Architecture, related to the Ministry of Housing and Urban Development, has introduced some criteria for selecting the vulnerable urban fabrics for re-development [12]. These criteria are vulnerability of buildings, size of houses and width of existing road network in each block. Based on this method, an urban fabric will be considered vulnerable if it meets one, two or all of these criteria. A summary about these criteria and related methods for recognition of old urban areas are presented in the following parts.

2.1. Vulnerability of Buildings

It is clear that the vulnerability of buildings is one of the most important parameters for evaluation of earthquake potential damages in urban fabrics. Different methods can be used in categorizing urban areas using this criterion. In Iran and based on the regulation of High Council of Urban Development and Architecture, the buildings can be categorized into three groups from low to high vulnerability considering the type, age and material of the structures [12]. In planning for rehabilitation, the first priority is related to highly vulnerable buildings; including mud brick structures, masonry building and buildings with weak structures. In each block the areas of these buildings will be evaluated and if their percentages is more than 50% of all buildings located in the block, the block is considered as highly vulnerable block.

Vulnerability of building is one of the main causes of earthquake damages in Iran's urban areas. In old urban fabrics, most buildings suffer from lack of resistance to earthquake shaking as most of them have been built many decades ago. In addition in old cities, many of houses which are made by traditional materials, specially mud brick, or built regardless to the structural codes or violating them. Mud-brick, 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 is still observable in the rural and some parts of poor urban areas. Performance of traditional adobe construction during numerous Iranian earthquakes has generally been poor [2]. Low material strength, poor work-manship, 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.

Some parts of Tehran also suffer from vulnerable and old buildings because of rapid urbanization and lack of strong rules and regulations for construction in some period of time (specially between 1941 to 1980, where the population has increased to more than 7 times as shown in Table (1)).

Table 1. Population and urban areas growth in Tehran since 1922 to 2006 [13].

Year	Urban Area (Km^2)	Population	Year	Urban Area (Km^2)	Population
1922	24	210.000	1980	370	5.443.000
1932	30	310.000	1986	567	6.042.000
1937	32	500.000	1991	588	6.475.000
1941	65	700.000	1996	621	6.758.000
1956	100	1.512.000	2000	621	6.960.000
1966	181	2.719.000	2006	621	7.711.000

Considering the vulnerability of the buildings and the above-mentioned criterion, the distribution of the highly vulnerable blocks in Tehran is shown in Figure (2).

2.2. Size of Houses Inside the Blocks

The size of houses in each block, including the building floor area and its open space, is considered as the second criterion for evaluation of vulnerable urban fabrics based on existing rules in Iran. In each block the number of houses having less than $100m^2$ areas are considered as vulnerable ones. If the number of these houses are more than 50% of the total houses in each block, then the block is considered as vulnerable.

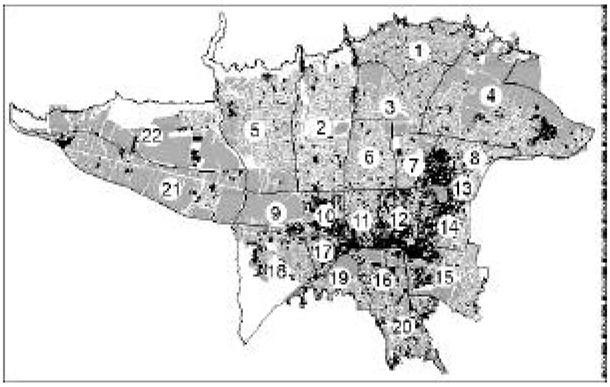

Figure 2. Distribution of highly vulnerable blocks in Tehran [14].

Obviously the size of individual houses can not directly demonstrate the vulnerability of the urban fabric, and in the literature, it is not common to use this factor for such purposes. In fact, a small house may perform well if it is simple in form and well-constructed. Although, this criterion may indirectly show the economic condition of the residents and population density at risks, which are important factors in earthquake risk evaluation. In this case, it would be better to replace this criterion with those directly related to socio-economic condition of urban fabrics. Considering this criterion, the distribution of vulnerable blocks in Tehran is shown in Figure (3).

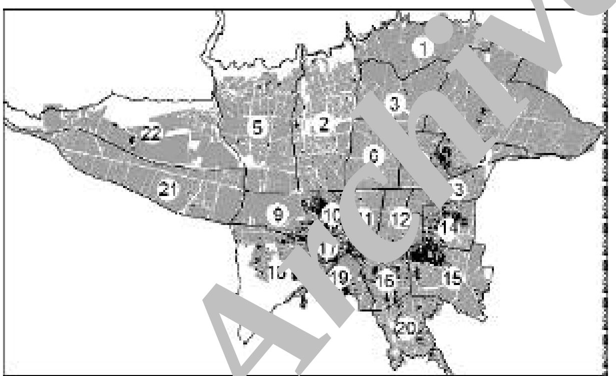

Figure 3. Distribution of blocks having more than 50% of small houses [14].

It is worth to say that considering this criterion, integrating small parcels for rehabilitation is now a priority for issuing permits in municipality for vulnerable buildings in Tehran and if owners apply for such integration, they may use some benefits such as exemptions from some types of taxes.

2.3. Width of Existing Road Network in Urban Blocks

This criterion is the third parameter introduced by the Iran's High Council of Urban Development and Architecture for evaluating the vulnerability of urban fabrics, showing access to the blocks and the risk of blockage after an earthquake. Based on this parameter, length of the roads with less than 6 meters width should be measured and compared with the total length of the roads exist inside the block. If the ratio is higher than 50%, then the block is considered as vulnerable.

Most of the old urban areas in Iran suffer from narrow roads and streets. 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. In Manjil (1990) and Bam (2003) earthquakes, nearly all narrow roads in the cities were partially or completely blocked and it caused considerable delay in rescue and relief operations.

In some parts of Tehran, specially in central and southern districts, some blocks are categorized as high priority for rehabilitation because of this problem, as shown in Figure (4). Figure (5) depicts the location of the blocks inside Tehran that meet the mentioned criterion.

The width of roads seems to be a secondary factor that affects mostly rescue and relief operations and is not directly a damage cause. However, sometimes this criterion has been considered in selection of vulnerable fabrics for rehabilitation in other countries as well. For example in Istanbul Metropolitan, based on the existing Disaster Management Master Plan, it is estimated that several thousands of buildings (residential or commercial) should be destroyed for

Figure 4. Dense populated area with narrow roads could be observed in old parts of Tehran.

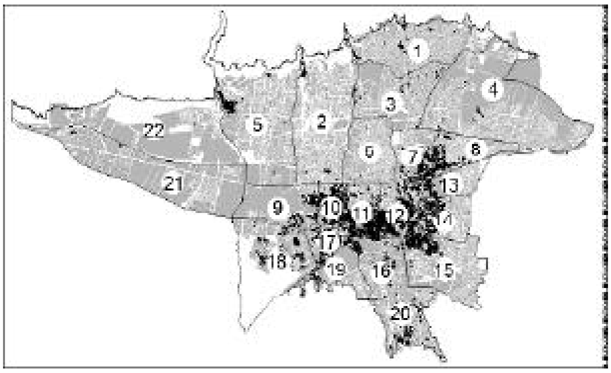

Figure 5. Distribution of blocks having more than 50% of narrow roads [14].

Table 2. The most vulnerable urban fabrics in Tehran based on the physical parameters.

District No.	Most Vulnerable Areas (ha)	District No.	Most Vulnerable Areas (ha)
1	64	12	593
2	19	13	73
3	25	14	258
4	8	15	246
5	12	16	149
6	5	17	240
7	237	18	103
8	144	19	22
9	146	20	137
10	428	21	7
11	352	22	1

widening the existing roads in middle to long term rehabilitation projects [15]. In addition in some earthquake vulnerable urban fabrics of Japan, such as Sumida ward in Tokyo, widening of passageways are one of the key policies for reducing earthquake risk [16].

Considering these three criteria that can be referred as physical parameters, the most vulnerable blocks which need immediate action for reconstruction and renovation are those having all three criteria as given in Table (2).

3. Vulnerability of Urban Fabrics in Earthquake Prone Zones

The above-mentioned method considers three criteria for evaluation of vulnerability of urban fabrics, but as discussed earlier, they are not sufficient for prioritizing urban fabrics for rehabilitation in earthquake zones and it is essential to consider some other parameters that are directly or indirectly related to earthquake and local conditions. These parameters will be discussed in the following parts and then some of them will be applied for evaluating the vulnerability of Tehran accordingly.

3.1. Seismic Hazards

Seismicity and distribution/mechanism of different types of faults in urban areas may affect the vulnerability of urban fabrics against potential earthquakes. These effects can be observed in different ways; including shaking level, possible rupture under the buildings or infrastructures, and difference in strong ground motion due to near or far-field effects, etc.

The seismicity of Tehran is also an important issue for any development or rehabilitation plans. As shown in Figure (6), several main and local faults exist in or around the city. Among them at least three

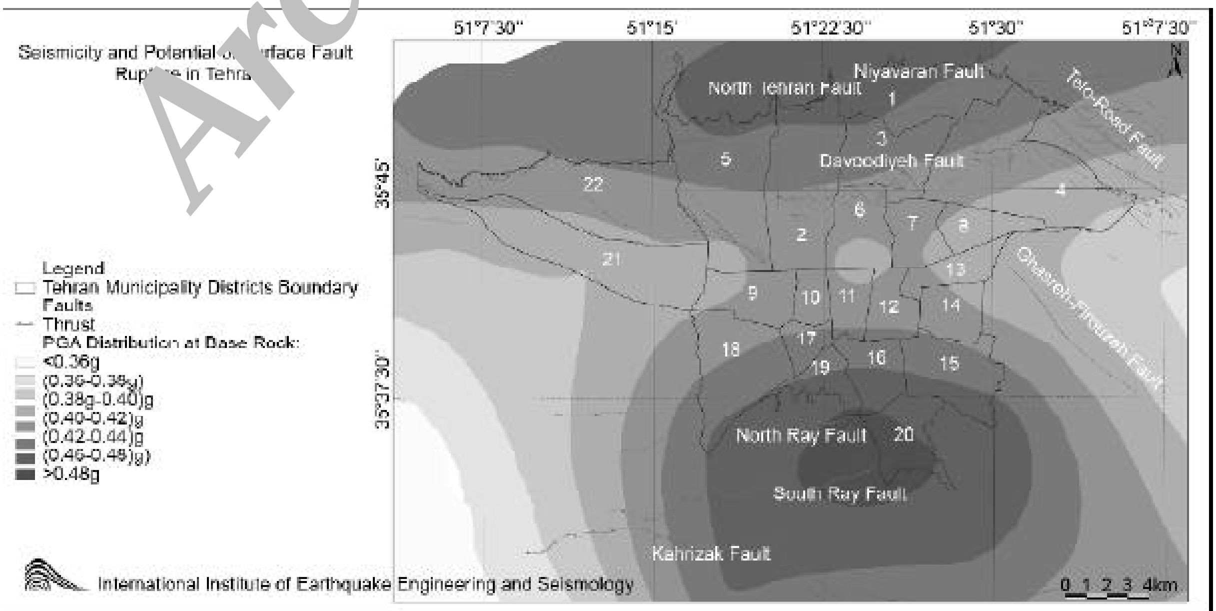

Figure 6. Seismic hazard map of Tehran [17].

active faults such as Mosha, North Tehran and Ray Faults, have surrounded the city and movement of each may cause strong earthquakes in Tehran. Moreover it is predictable that in case of an earthquake, the displacement of local faults may cause rupture in the ground surface, so the buildings constructed on them may be damaged more seriously.

Recently, the seismicity and fault rupture potential in Tehran have been considered in the new version of Tehran Master Plan and based on the existing rules, their effects should be taken into account in any urban planning and development projects [17]. This parameter has been applied in this research as a measure for identifying priorities in rehabilitation of vulnerable urban fabrics.

3.2. Geological Hazards

Geological hazards such as liquefaction, landslide and rockfall which can be induced or triggered by earthquake motions may also increase the vulnerability level of urban fabrics. Table (3) presents some of the events in the Alborz region accompanied with landslides and rockfalls. Perhaps the worst case was related to Manjil earthquake (1990), in which big landslides covered some villages and residential areas and several hundreds of people were buried under the debris. Also, in Firouz Abad-Kojour earthquake (2004), several residential buildings were destroyed by rockfalls.

Besides liquefaction and landslides, the effects of other geotechnical instabilities are also important. For example, in Bam earthquake, land subsidence due to collapse of Qanats (underground irrigation tunnels) caused severe damage to some buildings and lifelines [19]. These examples show that the urban fabrics located in the vicinity of geological hazard zones normally experience more severe damage in earthquakes. Hence the vulnerability of these sites are higher than the similar fabrics located elsewhere.

The geological hazards in some parts of Tehran can also affect the vulnerability of urban fabrics. In the northern parts of Tehran several building are constructed on the mountains and hills that are in danger of rockfall and local landslides, as shown in Figures (7) and (8). Also, in southern parts, due to the high level of water table, there is the risk of liquefaction in some areas, see Figure (7). Moreover due to the existence of more than 370 underground hidden channels of Qanats in Tehran, different parts of the city may experience some sinkholes at the time of potential earthquakes [20].

3.3. Site Effects

Considering the geological conditions of different parts of the cities, the intensity of earthquake can be changed due to the site effects. In such condition, even if the existing buildings have same structures and quality of construction, the damages of a potential earthquake could be different; as each part may experience different levels of *PGA*. Therefore, in planning for rehabilitation of urban areas (assuming that other conditions are similar), the first priority will be related to the areas that may experience higher intensity. This shows that the urban planners should use the Geotechnical Microzonation Maps as a base for preparing rehabilitation plans of the city [21]. However, they are not much interested in these subjects, since planners normally consider functional and aesthetical aspects, and not natural hazards, into account for zoning [22].

Site effects have caused different damage level

Table 3. Some of the landslides and rockfalls in Alborz region earthquakes [18].

Location	Date	Type of Instability	Magnitude	Main effects
Ray-Taleghan	958	Landslide	7.7	Burial of a Village under Debris
Chardangeh	1127	Landslide	6.8	Movement of a Village
Gorgan	1470	Landslide and Rockfall	5.5	Burial of a Village under Debris
Haraz-Talaroud	1830	Rockfall	7.1	Blockage of Haraz and Talaroud Roads
Ah-Mobarak Abad	1930	Landslide	5.2	Damage to Villages and Roads
Talaroud	1935	Landslide and Rockfall	5.8	42 Death Due to Landslide and Rockfall
Baijan	1983	Landslide and Rockfall	5.2	Damage to Villages and Roads
Manjil	1990	Landslide and Rockfall	7.7	Around 180 Landslides and Thousands Rockfalls
Firouz Abad - Kojour	2004	Landslide and Rockfall	6.3	Damages to Villages and Roads

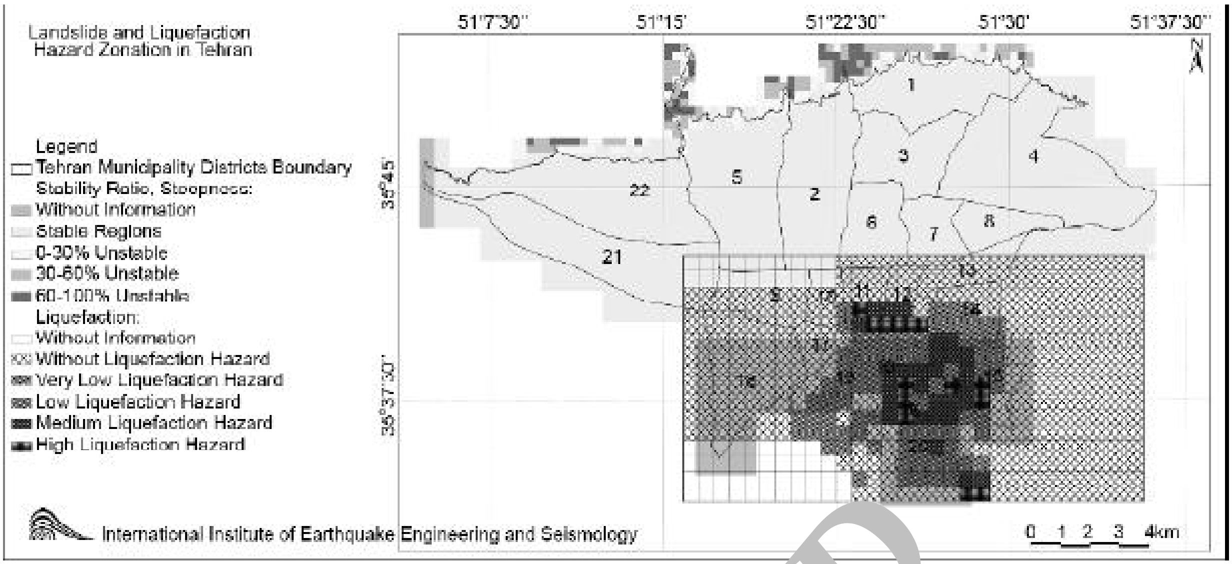

Figure 7. Geological hazard map (landslide, rockfall and liquefaction) in Tehran [17].

Figure 8. Construction of vulnerable structures on hills and slopes in North of Tehran.

in previous earthquakes of Iran. For example in Bam earthquake of 2003, geological condition caused amplification in some parts and intensified the buildings damage at those parts. In that case, the highest levels of damages were related to the sites with shallow and medium depth soils which caused considerable amplification in high frequency range [23]. The evaluation of Tehran geotechnical micro-zonation map also show that the city has got considerable potential for ground motion amplification as shown in Figure (9).

3.4. Disaster Management Capacity

Besides the above-mentioned issues, there are some other parameters that directly or indirectly affect

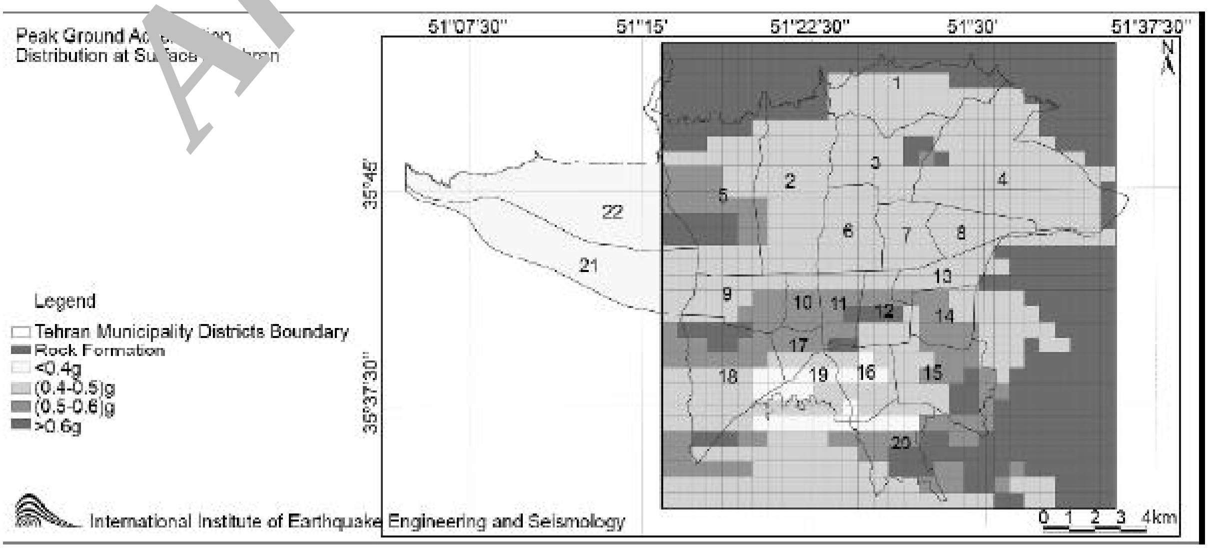

Figure 9. Peak ground acceleration distribution at surface in Tehran [17].

the vulnerability of urban fabrics. These items are discussed in the following parts:

3.4.1. Emergency Response Facilities

Immediately after an earthquake and during the first hours, the emergency response activities can save the lives of many victims trapped under the debris or rescued by the people or rescue teams. Therefore, the placement of related facilities, including civil defense installations, emergency management centers, fire stations, hospitals, mass emergency shelters, police stations, etc, in urban fabrics is important for providing necessary responses and cares [24]. Lack of such facilities or shortages in their functionality after the previous Iran's earthquake caused serious difficulties for the victims [25].

The distribution and vulnerability of emergency response facilities are different in Tehran's districts. In some places there are enough numbers of health centers, fire stations, and other facilities assisting emergency response while in other areas the shortages of these facilities are quite obvious. Therefore, the level of services in these areas could be different at the time of earthquake and this fact should be considered in urban rehabilitation by city planners for earthquake risk reduction. Of course, during the recent years some activities have been carried out by Tehran Municipality to improve the existing condition including establishment of "Disaster Management Bases" in different parts of Tehran to provide necessary emergency services after an earthquake. Such facilities could be considered as managing facilities at the time of crisis that may reduce the negative impacts of an earthquake.

3.4.2. Evacuation Places

Evacuation is an important issue for saving lives of survivors and reducing the negative impacts of earthquakes during the first 72 hours after the event, when there is the risk of fire, strong aftershocks or landslide. If people can not be properly evacuated to safe evacuation places through proper evacuation routes, human casualties can be increased. Therefore, allocating the safe evacuation places before an earthquake can reduce the vulnerability level of urban fabrics. Safe public buildings, such as mosques or schools, or proper open spaces, like parks or playgrounds, could be considered as potential evacuation sites in urban fabrics. In Tehran several projects for development of local and regional evacuation places have been carried out; details of which can be found in [26-27]. A sample of emergency evacuation map is illustrated in Figure (10).

Figure 10. Emergency evacuation map (in Farsi) prepared for one of the Maha[illegible] (neighborhood) in Tehran [27].

3.4.3. Industrial Hazards

The vulnerability of urban areas may also be increased by the presence of hazardous facilities such as gas pipelines, electricity poles and power plants, tank farms, petrol or gas stations, chemical material storages, chemical or medical research centers, etc. Damages to these facilities during earthquakes may cause explosion, fire or even diffusion of poisonous gases in the areas as observed in some previous earthquakes such as Kocaeli, Turkey (1999) [28], which can also affect the 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 taken for assuring safety of these areas. Nowadays, the displacement of these sites from the residential urban fabrics is a general policy for urban renovation in most of the countries, examples can be found in [29-30].

3.4.4. Other Parameters

Some other parameters can also be considered when evaluating the vulnerability of urban fabrics against earthquakes. Population density, percentage of vulnerable population (old, handicapped, infants, children, etc), as well as socio-economic conditions, such as level of awareness and preparedness of the residents are some of these parameters which their impacts need to be evaluated in more details by further researches.

Moreover, in big cities such as Tehran, some other parameters may also affect the vulnerability of urban fabrics which requires further evaluation including:

- Mixed construction and overly flexible steel framing which leads to excessive distortion and interference behavior in buildings when they are shaken;
- Poorly stabilized and excessively ornate facades, which will collapse onto people as they run out of houses;
- In many streets buildings of different size are juxtaposed in close proximity which will sway with different fundamental periods and batter each other down.

3.5. Evaluating the Vulnerability of Urban Fabrics in Tehran Based on Earthquake Related Parameters

Among the above-mentioned subjects, some of them have been considered in this study to evaluate the vulnerability of Tehran urban fabrics against a potential earthquake as follows:

3.5.1. Building Damage

The damage of buildings was evaluated based on chosen earthquake scenarios as introduced in *CEST* and *JICA* [4]. Among the main active faults surrounding Tehran, Ray Fault and North Tehran Fault (*NTF*) generate the strongest earthquakes impacts with different *PGA* in southern and northern micro zones. In this study, the maximum amounts of *PGA* was considered for each microzone and therefore, for the northern parts of Tehran, the estimated *PGA's* of *NTF* fault were applied while for southern and central zones, the *PGAs* generated by Ray Fault were considered. Having this input as the shaking parameter, the vulnerability of the existing buildings was evaluated for different types of structures by using fragility curves developed based on data related to the previous earthquakes in Iran [31]. Then building damage ratio that is, number of damaged building in each microzone per total buildings, has been evaluated and reflected into *GIS* database.

3.5.2. Evacuation

Parameters such as availability of evacuation places, disaster weak population ratio (handicapped people and those aged more than 65/less than 5 years), and road blockage ratio (ratio of the roads blocked by debris due to the collapse of buildings), were considered for categorizing the vulnerable urban fabrics.

3.5.3. Secondary Disasters

In this study, the location and effects of hazardous facilities such as chemical storages, chemical factories, flammable or explosive materials like gas station, high pressure natural gas pipelines and facilities, etc, as well as the electricity network were considered to identify vulnerable urban areas.

Considering these parameters, the results were classified into 5 groups as given in Table (4) and then each component was weighted to analyze the integrated vulnerability of Tehran. For this purpose, the vulnerability of buildings and evacuation was given the value of 2 and secondary disaster value of 1 based on previous experiences and engineering judgments. Based on the results, the vulnerability of each microzone was classified into five levels from 5 for the most vulnerable areas to 1 showing comparatively safe places. Figure (11) shows the distribution of these areas in Tehran.

Although the most vulnerable areas of Tehran can be recognized by this map, however, it is not clear

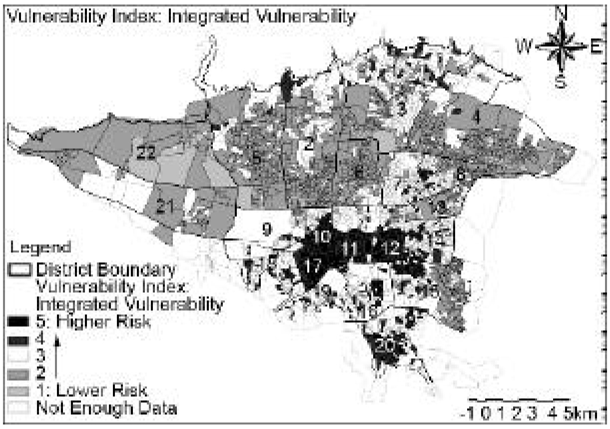

Figure 11. Integrated vulnerability Index in Tehran [26].

Table 4. Scoring of different parameters for evaluation of earthquake vulnerability in urban fabrics in Tehran.

Evaluated Parameters/ Score for Each Item	1	2	3	4	5
Vulnerability of Buildings	Very Low	Low	Moderate	High	Very High
Evacuation Conditions	Good	Fair	Moderate	Poor	Very Poor
Secondary Hazards	Very Low	Low	Moderate	High	Very High

which parameter is the key element in each district in order to make a decision for improvement measures. In order to get such information, this has been analyzed by using a triple symbol for showing the condition in each parameter. For this purpose, each of the explained parameters was given a symbol *A* or *B*, letter *A* representing the low risk areas and *B* for the high risk. Table (5) explains how the 3 character symbols could describe the low or high risks in each microzone. For instance the symbol *AAA* shows that at the relevant zones, all three parameters, which are respectively related to vulnerability of buildings, evacuation and secondary disaster, are in proper condition, while the symbol *BBB* are for the worst cases which suffer from all indicated criteria. The results of this classification are shown in Figure (12).

Based on this analysis, urban fabrics of Tehran are classified at sub-district levels (Nahiye) into three categories, namely "Priority Improvement Area", "Improvement Area" and "Built-up Area" in terms of priority for improvements as shown in Figure (13) and explained in Table (6). In this table the basic approaches for reducing the risk in these areas are also explained, as follows:

Table 5. Evaluation criteria for urban characteristics.

Index	Characteristics of Districts Management
AAA	Relatively Less Vulnerable Urban Structures
AAB	High Risk on Secondary Disaster
ABA	High Risk on Evacuation Possibilities
BAA	High Risk on Building Collapse
ABB	High Risk on Evacuation Possibility and Secondary Disaster
BAB	High Risk on Building and Secondary Disaster
BBA	High Risk on Building and Evacuation Possibilities
BBB	High Risk on All Aspects

- **Priority Improvement Areas:** These areas are the most vulnerable urban fabrics having many vulnerable buildings and suffer from lack of evacuation places, evacuation roads and so on. These areas need urgent actions with emphasis on area re-development, because most parts are covered by old and high-density buildings as well as limited open spaces for evacuation and narrow streets occupied by parked cars.
- **Improvement Area:** Improvement Areas are also high risk places which are expected to be seriously damaged by the potential earthquake. These areas include many vulnerable zones susceptible to building collapse, but not so seriously vulnerable to evacuation index, or if they are vulnerable in evacuation index, they are not assessed as seriously vulnerable to building collapse. The basic strategy for risk reduction here is not re-development, but the improvement of disaster prevention facilities at community level including developing evacuation places, evacuation routes, and so on.

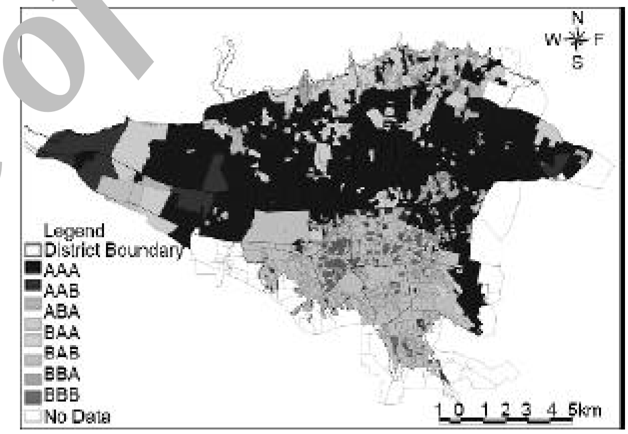

Figure 12. Characteristics of vulnerability in different micro-zones in Tehran [26].

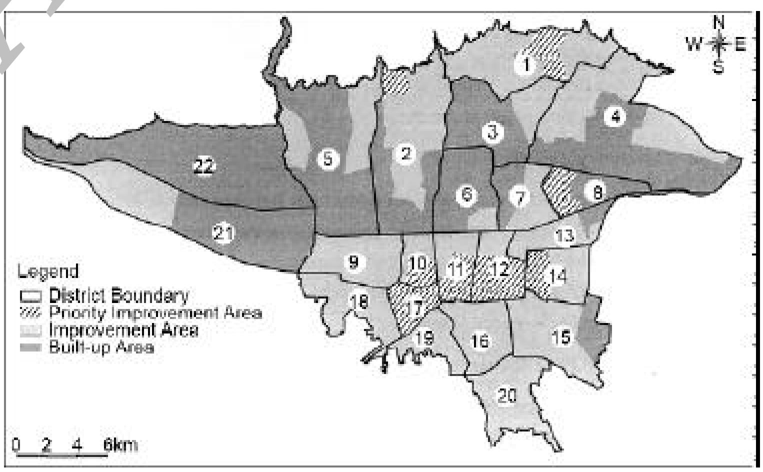

Figure 13. Priorities for urban development [26].

- **Built-up Area:** This type of block is not considered to be in big danger from two viewpoints of building collapse and evacuation. They consist of proper buildings and good evacuation index. Built-up Area is not seriously vulnerable compared to other mentioned areas, but they need to be improved by individual disaster prevention measures such as individual building retrofitting and so on.

The result of this analysis is summarized in Table (7) for different districts of Tehran.

4. Discussion and Results

Table (8) compares the conditions of most vulnerable areas in different districts of Tehran evaluated by

Table 6. Major features of three categorized areas.

Vulnerability/ Characteristics	Basic Approach	Supporting System
1. Priority Improvement Area Vulnerability • Building Collapse Index-B Evacuation Index-B Characteristics • Out of the coverage of regional evacuation place • High density • Old building	Regional Level • Large-scale area re-development	• Area re-development • Dedicated fund for urban re-development system • Financial cross-subsidization system • Legal process for formulating consensus among residents • Cadastral-based land registration and appropriate property assessment system • Taxation systems to capture accrued benefits from beneficiaries
2. Improvement Area Vulnerability • Building Collapse Index-B and Evacuation Index-A • Building Collapse Index-A and Evacuation Index-B Characteristics • Not all area inside the coverage of regional evacuation place • Middle to high density	District Level • Development for disaster prevention at community level • Securing of Community Evacuation Space • Improvement of Evacuation Route • Small-scale land re-development	• Dedicated fund for urban re-development • Practical land readjustment system • Legal process for formulating consensus among residents • Enforcement of earthquake-resistant design codes and inspection system to secure design-compliant building act
3. Built-up Area Vulnerability • Building Collapse Index-A • Evacuation Index-A Characteristics • Inside of coverage of regional evacuation place • Low to middle density	Individual Level • Individual implementation for disaster prevention • Strengthening of individual buildings	• Enforcement of earthquake resistant design codes and inspection system to secure design-compliant building act • Introducing incentive system to promote strengthening of buildings

Table 7. The level of vulnerability in different districts of Tehran [12].

District	Total Areas (ha)	Priority Improvement Area (ha)	Improvement Area (ha)	Built-Up Area (ha)
1	3462	596	2866	0
2	4968	302	2872	1794
3	2945	-	659	2286
4	7260	-	3303	3957
5	5915	-	1742	4173
6	2149	-	279	1870
7	1541	-	868	673
8	1327	456	-	871
9	1960	-	1960	0
10	808	282	526	0
11	1189	562	627	0
12	1359	995	364	0
13	1391	-	1026	365
14	1459	460	999	0
15	2852	-	2228	624
16	1649	-	1649	0
17	829	829		0
18	3794	-	3794	0
19	1152	-	1152	0
20	2033	-	2033	0
21	5208	-	1879	3329
22	6154	-		6154

Table 8. Comparison of the vulnerability of urban fabrics in various districts of Tehran based on two different approaches.

District	Total Areas (ha)	Highly Vulnerable Areas Using First Method (ha)	Highly Vulnerable Areas Using Second Method (ha)
1	3462	64	596
2	4968	19	302
3	2945	25	-
4	7260	8	-
5	5915	12	-
6	2149	5	-
7	1541	237	-
8	1327	144	456
9	1960	146	-
10	808	428	282
11	1189	352	562
12	1359	593	995
13	1391	73	-
14	1459	258	460
15	2852	246	-
16	1649	149	-
17	829	240	829
18	3794	103	-
19	1152	22	-
20	2033	137	-
21	5208	7	-
22	6154	1	-

using the above-mentioned two methods. The results show that without considering the effects of earthquake related parameters, the priorities for improvement of urban fabrics can not be evaluated in a reliable manner. Therefore, it seems that the currently used regulations for classification of vulnerable urban fabrics in Iran should be revised in order to consider the earthquake related parameters as key elements. It is also necessary to make further researches on the impacts of each individual physical and social parameters on vulnerability of urban fabrics, and to assess the proper weighting methods for evaluating their effects on the vulnerability.

Acknowledgments

Some parts of this research carried out in cooperation with the study team of Japan International Cooperation Agency (*JICA*). Their technical and financial supports are appreciated.

References

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

2. Maheri, M.R., Naeim, F., and Mehrain, M. (2005). “Performance of Adobe Residential Buildings in the 2003 Bam, Iran, Earthquake”, *Earthquake Spectra*, **21**(S1), S125-S136, EERI.

3. Bam Earthquake Statistics (2003). Statistic Center of Iran, Tehran, Iran.

4. 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.

5. Nateghi-A., F. (2001). “Earthquake Scenario for Mega-City of Tehran”, *Disaster Prevention and Management*, **10**(2), 95-100.

6. Amini Hosseini, K. and Hosseini, M. (2007). “Evaluation of Old Urban Structures and Emergency Road Networks Vulnerabilities to a Potential Earthquake in Tehran”, *Proc. of 5th International Conference of Seismology and Earthquake Engineering (SEE5)*, Tehran, Iran.

7. Quigley, J.M. (1998). “The Use of Economics, Engineering, and Statistical Information to Invest in Seismic Safety”, *Invitational Workshop Proc.*, Defining the Links between Planning, Policy Analysis, Economics, and Earthquake Engineering, Report No. PEER-98/04, Pacific Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley.

8. Rutherford, A. and Chekene, E. (1990). “Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings”, Prepared for the City and County of San Francisco, Department of City Planning.

9. Recht Hausrath and Associates (1990). “Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings: Socioeconomic and Land Use Requirements”, Prepared for the San Francisco Department of City Planning.

10. Imamura, T. (2003). “Developing and Implementing Building Codes: Experiences from Disasters, GP/DRR Side Event Building Code Enforcement and Dissemination Ministry of Land”, Infrastructure and Transport (MLIT) of Japan.

11. Novakowski, N. (2005). “Land Use Planning in Earthquake Prone Areas”, Fatih University, Department of Geography, Istanbul, Turkey.

12. 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).

13. Amini Hosseini K and Jafari, M.K. (2007). "Development Guidelines for Disaster Risk Management", *Proceeding of 5th International Conference of Seismology and Earthquake Engineering (SEE5)*, Tehran, Iran.

14. Tehran Research and Planning Center (2004). "Evaluation of Old Urban Fabrics in Tehran", Center for Tehran Master and Comprehensive Plans, Tehran, Iran (In Farsi).

15. Metin, O. (2007). "Istanbul Earthquake Mitigation and Transformation Plan", *Proceedings of the Earthquake Megacities Initiative*, Asia Megacities Forum AMF07, Jacarta, Indonesia.

16. Kumagai, Y. and Nojima, Y. (1999). "Urbanization and Disaster Mitigation in Tokyo, in Crucibles of Hazard: Mega-Cities and Disasters in Transition", Edited by: J.K. Mitchell, The United Nations University Press.

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

18. Jafari, M.K. and Mahdavifar, M.R. (2002). "Earthquake Triggered landslides in Iran", Technical Report, International Institute of Earthquake Engineering and Seismology, Tehran, Iran.

19. 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).

20. Montazer Ghaem, S. and Noroozi, R. (2007). "Qanat Distribution in Tehran", Technical Report, Tehran Disaster Mitigation and Management Organization, Tehran, Iran.

21. Bostenaru, M. (2005). "Multidisciplinary Co-Operation in Building Design According to Urbanistic Zoning and Seismic Microzonation", *Natural Hazards and Earth System Sciences*, (5), 397-411.

22. Bademli, R. (2001). "Earthquake Mitigation and Urban Planning in Turkey", In: Komut, E.M.: Natural Disasters: Designing for Safety, Chamber of Architects of Turkey, Ankara, 58-64.

23. Jafari, M.K., Ghayamghamian, M.R., Davoodi, M., Kamalian, M., and Sohrabi, A. (2005). "Site Effects of the 2003 Bam, Iran, Earthquake", *Earthquake Spectra*, **21**(S1), S125-S136, EERI.

24. "Primer on Natural Hazard Management in Integrated Regional Development Planning" (1991). Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs Organization of American States, Washington, D.C.

25. Movahedi, R. (2005) "Search, Rescue and Care of Injured Following the 2003 Bam, Iran Earthquake", *Earthquake Spectra*, **21**(S1), S475-S486.

26. Tehran Disaster Mitigation and Management Organization (TDMO) and Japan International Cooperation Agency (JICA) (2004). "The Comprehensive Master Plan Study on Urban Seismic Disaster Prevention and Management for the Greater Tehran Area in the Islamic Republic of Iran", Final Main Report, JR, 04-039, Tehran, Iran.

27. Tehran Disaster Mitigation and Management Organization (2008). "Evacuation Map and Guidelines for Selected Mahalleh of Tehran", Tehran, Iran.

28. Bendimerad, F., Johnson, L., Coburn, A., Rahnama, M., and Morrow, G. (1999). "Kocaeli, Turkey Earthquake", Event Report, RMS Reconnaissance Team.

29. COMAH (1999). "The Control of Major Accident Hazards Regulations", http://www.hse.gov.uk/comah, UK.

30. Nivolianitou, Z., Papazoglou, I., and Bonanos, G. (2004). "Environmental Indices in Land Use Planning Around Hazardous Industrial Sites, Systems Reliability and Industrial Safety Laboratory (SRISL)", Institute of Nuclear Technology-Radiation Protection, Greece.

31. Tavaloki, B. and Tavakoli, S. (1993). "Estimating the Vulnerability and Loss Function of Residential Buildings", *Journal of the Int. Society for the Prevention and Mitigation of Natural Hazards*, **7**(2).