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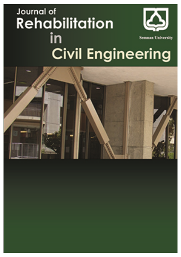

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Probabilistic Assessment of Earthquake Damage and Loss for the City of Tehran, Iran

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ABSTRACT

Tehran is one of the densely populated metropolises located in earthquake-prone regions. Tehran, the population of which surpasses 8 million people, is the most populated area in Iran. There are historical evidences confirming that catastrophic earthquakes have destroyed the city in past years. In the present paper, our study covers all parts of Tehran because there is the potential of significant earthquake damage and loss for the entire city. In other words, the development of high-rise building construction in the northern part, the high density of population in the southern area including old masonry buildings, and the existence of important structures in central regions, prevent us from omitting any particular part of the city from damage assessment process. We have used two sets of last available formal data published in 1996 and 2006. To consider the influence of soil conditions, Tehran has been divided into 1246 sub regions; however, in our study the results have been presented using municipality regions and in cumulative manner. Since there is no acceptable statistical data involving estimation of non-structural damage, only structural damages have been assessed. The open source software SELENA is applied to perform probabilistic loss estimates. Due to the lack of studies providing required information from structural point of view in our country, and the existence of similarity between structural codes of Iran and that of United States, HAZUS-MH (Hazard Us – Multi Hazard Loss) structures coefficients are used. According to the results, from 1996 to 2006, the mean damage ratio and number of casualties have been reduced, while the economic loss has been increased.

1. Introduction

Iran is situated over one of the seismic zones of the world, the Himalayan-Alpide seismic belt. The occurrence of devastating earthquakes has imposed notable damages to the buildings and lifelines, and, unfortunately, has caused huge loss of human life. Robust assessment of seismic damage and loss for Tehran, the capital city of Iran, is compulsory due to some major reasons:

- The population of Tehran is over 8 million people, which makes it the center of main political, economic, social, and cultural activities in Iran.
- The results of previous seismic hazard analysis of region show the high probability of occurrence of severe earthquakes in future. Considering the historical background of earthquakes and the existence of major faults near and within the city, the probability of occurrence of an earthquake with a moment magnitude M_w greater than 7 is seriously high.

The city of Tehran is situated on the south plateau of central Alborz Mountain, and over alluvium sediments. Its southern parts lie roughly on the North-west corner of Iranian large desert (with mean altitude of 1300 m above sea level). The distance of the nearest mountain to the city is less than 10 km (Tochal Mountain with altitude approaching 3933 m) [1]. To quantify the region's seismic hazard, a peak ground acceleration PGA of 0.35 g for a rock site corresponding to the 10% probability of exceedance in 50 years (the return period of 475-year) is proposed by Iranian Code of Practice for Seismic Resistant Design of Buildings [2]. Tehran is divided into 22 municipality zones as is sketched in Fig. I. We employ this zoning approach in the later processing of structural information and population data; however, some subdivisions on these zones may be used.

As it is mentioned earlier, the special conditions of Tehran have caused rapid growth in population and construction. More than 95.4% of structures in 1996 were in one of steel, concrete, and masonry categories [3]. Construction of steel structures is more prevalent, and the total building's area of which is 6 times greater than that of other categories [4]. These structures were distributed in all parts of Tehran in 1996. After execution of earthquake retrofitting project (1996-2006), masonry buildings have been mainly substituted with steel structures [4]. Therefore, the total building area assigned to steel structures is more than 70% in regions 3, 4, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 19, and 20 in 2006 [4]. Concrete structures are mainly located in northern zones. More than 50-57% of building areas in regions 5, 22, and 1, are constructed in 1996-2006. Most of latter structures are concrete buildings. Masonry structures chiefly are located in older zones covering central and southern parts of the city [3]. From 1996 to 2006, the total area of masonry buildings has been decreased. In 2006, the highest density of masonry buildings is 36% for regions 17 and 18 [4]. Although the progress of substitution of masonry buildings with steel and concrete structures has been considerable, still, a large proportion of casualties in severity levels 3 and 4 are related to masonry structures. In 1996, 68%, 26.5%, and 5.5% of buildings had 1-3, 4-8 and more than 8 stories, respectively [3]. 1-3 story buildings have a rather uniform distribution in all regions, but the concentration of 4-8 story buildings is in central parts. Structures having more than 8 stories are mainly found in northern zones [3]. Since 1996, residential buildings having more than 4 stories have constituted the major part of construction projects in Tehran [4]. In 2006, 41%, 37%, and 22% of structures had 1-3, 4-8 and more than 8 story, respectively (based on built area) [4]. Although there is not any formal census indicating the type of earthquake-resistant systems of structures used in different regions, studying issued construction licenses, we can state that among steel structures, 20% of systems are moment frames, 60% are braced frames, and 20% are cast in place concrete shear walls. In concrete structures, application of different systems depends on the height of the structure. 80% of 1-3 story buildings, 50% of 4-8 story, and 10% of buildings with more than 8 stories are moment frames, while the rest are braced frames. 60% of masonry buildings have 1 or 2 stories, and 40% of them have more than 3 stories.

The last severe earthquake has occurred in the 1830. Therefore, the likelihood of occurrence of next severe earthquakes is rather high. In this study, to consider of seismic hazard parameters, spectral acceleration is used. One can obtain the shear wave velocity in different regions from Fig 2.

Here, we aim to calculate the structural damage and estimate the earthquake loss for the city of Tehran using the open-source software tool SELENA [6]. Because of the paucity of studies providing needed information from structural point of view in our country, and the existence of similarity between structural codes of Iran and those of United States, HAZUS-MH structures coefficients are used. In the last 10 years, the reduction of seismic risk in Tehran has been the main country's macroeconomic policy [4]. We have used two sets of last available formal data published in 1996 and 2006 to evaluate the reduction of seismic risk. Table 1 presents the details of some historical disastrous earthquakes occurred in Tehran.

Fig. 1. Overview map of the city of Tehran with 22 municipality zones

Table 1. Historical earthquakes occurred in Tehran [3]

Year	Month	Day	Mw	Latitude (degree)	Longitude (degree)	Epicentral distance* (km)	Assumed PGA (gal)
855	-	-	7	35.6	51.5	12	412
958	2	23	7.7	36	51.1	41	161
1177	5	-	7.1	35.7	50.7	68	63
1665	-	-	6.4	35.7	52.1	59	44
1830	3	27	7	35.8	51.7	25	208

*Epicenteral Distance is from Ferdowsi square.

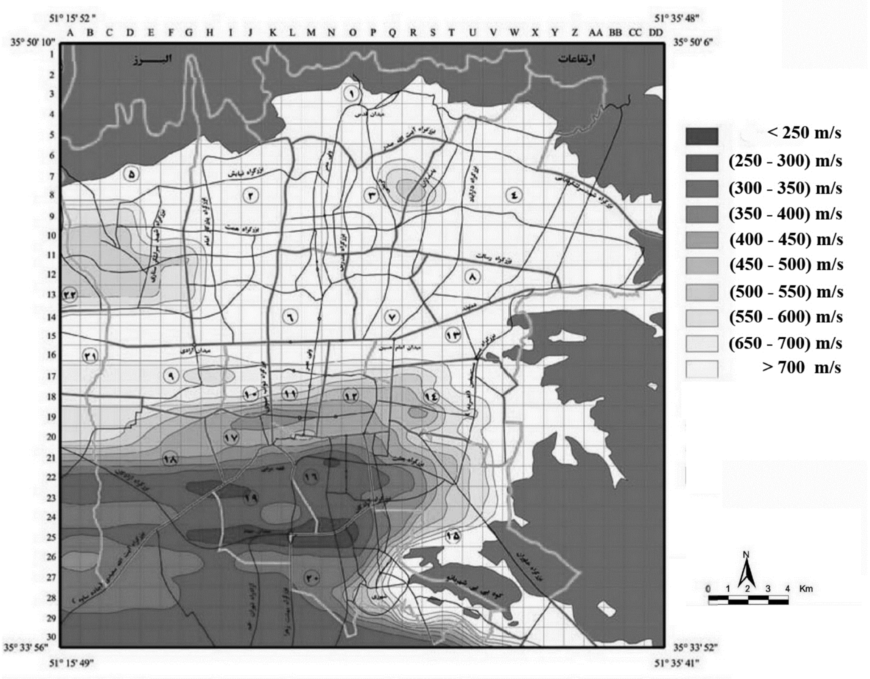

Fig. 2. Soil shear wave velocity of the city of Tehran [5]

2. Compilations of data

2.1. Building inventory

Up to 2012, Iran's population and housing census has been conducted every ten years [4]. The latest information is developed until 2006. According to the HAZUS-MH classification of structures [7], there are 17 types of building in Tehran, the characteristics of which are consistent with HAZUS-MH Structures. These structures are shown in Table 2. Structures are classified in three categories: steel, concrete, and masonry. Fig. 3 and 4 depict the area corresponding to each type of buildings. Since occupancy classes are reported in formal census in term of building area; In the present work, 6 major occupancy classes: residential, education, commercial (retail trade, personal and repair services), hospital and medical office, and government are considered. Since there is no information suggesting buildings age in previous censuses, all steel and concrete structures are assumed moderate-code buildings, while masonry structures are in low-code design level.

2.2. Demographic information and casualty model

Fig. 5 illustrates the distribution of population among different zones. From 1996 to 2006, more than 800,000 people have been added to the population of Tehran [4]. We have used different occupancy classes to calculate MDR[1] and economic losses. The population should be distributed using different zones and occupancy types. Due to the lack of sufficient formal data describing this distribution, probable earthquake casualties are calculated just in 2:00 a.m. One should keep in mind that the latter assumption means that the residential occupancy plays a significant role in the development of casualty model. The HAZUS methodology has been manipulated to estimate the probable earthquake casualties.

2.3. Development of Economic Loss Model

In recent years, many public and government buildings have been retrofitted in Iran. Therefore, the costs of rebuilding of structures

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[1] Mean Damage Ratio

in earthquake-stricken areas have been estimated. These costs vary according to the type and height of structures. Table 3 presents a summary of mentioned costs. Retrofitting and rehabilitation of buildings after earthquake differs based on damaged level. In practice, costs of retrofitting equal 10, 20, 40, and 60 percent of those of rebuilding procedure for slight, moderate, extensive, and complete damage levels, respectively.

A detailed description of the "HAZUS-MH" model building types are given in FEMA (2003) [7].

Table 2. Model Building Types (7)

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Meter
1	S1L	Steel Moment Frame	Low-Rise	1-3	2	8
2	S1M		Mid-Rise	4-7	5	20
3	S1H		High-Rise	8+	13	52
4	S2L	Steel Braced Frame	Low-Rise	1-3	2	8
5	S2M		Mid-Rise	4-7	5	20
6	S2H		High-Rise	8+	13	52
7	S4L	Steel Frame with Cast-in-Place Concrete Shear Walls	Low-Rise	1-3	2	8
8	S4M		Mid-Rise	4-7	5	20
9	S4H		High-Rise	8+	13	52
10	C1L	Concrete Moment Frame	Low-Rise	1-3	2	8
11	C1M		Mid-Rise	4-7	5	20
12	C1H		High-Rise	8+	13	52
13	C2L	Concrete Shear Walls	Low-Rise	1-3	2	8
14	C2M		Mid-Rise	4-7	5	20
15	C2H		High-Rise	8+	13	52
16	URML	Unreinforced Masonry Bearing Walls	Low-Rise	1-2	1	5
17	URMM		Mid-Rise	3+	3	11.6

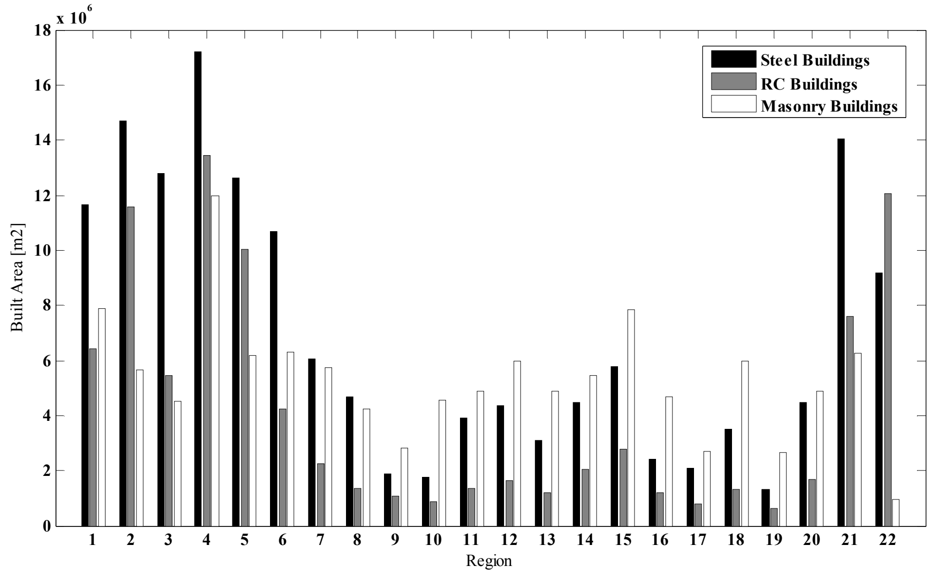

Fig. 3. Built area of steel, concrete, and masonry structures in Tehran's regions In 1996 (square meters) [3]

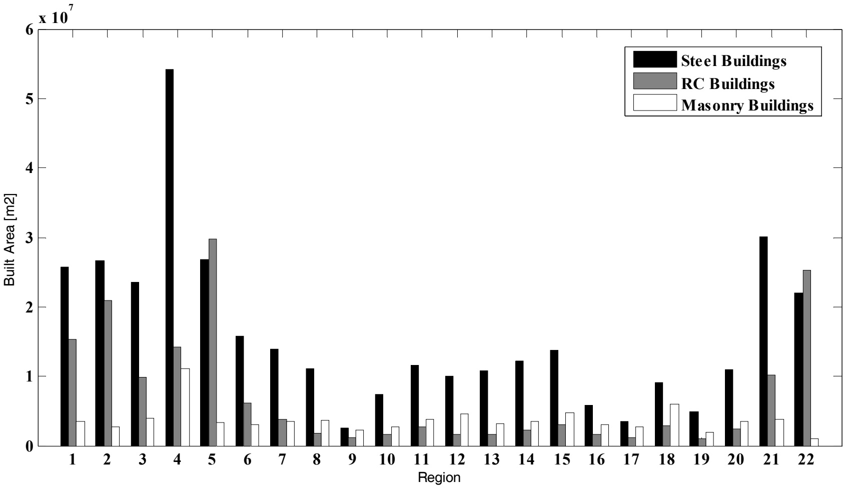

Fig. 4. Built area of steel, concrete, and masonry structures in Tehran's regions In 2006 (square meters) [4]

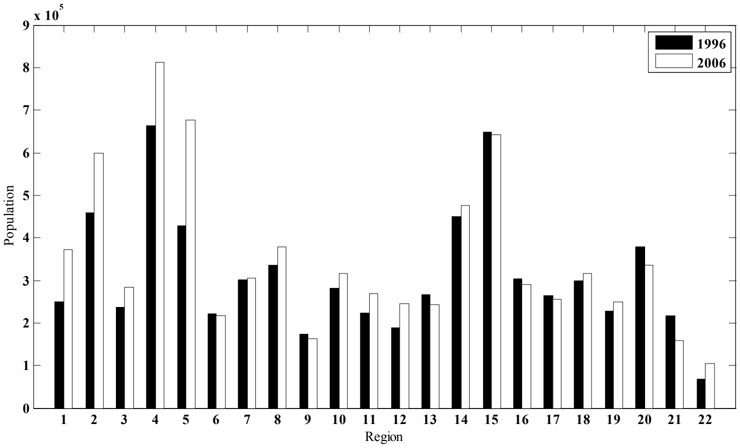

Fig. 5. Population of Tehran's regions in 1996 [3] and 2006 [4]

Table 3. New building construction cost (Dollars per square meter)

Occupancy	s1l	s1m	s1h	s2l	s2m	s2h	s4l	s4m	s4h
Residential	333.2	333.2	499.8	416.5	416.5	499.8	333.2	333.2	499.8
Commercial	333.2	333.2	499.8	416.5	416.5	499.8	333.2	333.2	499.8
Hospital	666.4	666.4	999.6	833	833	999.6	666.4	666.4	999.6
Repair service	333.2	333.2	499.8	416.5	416.5	499.8	333.2	333.2	499.8
Government	433.16	433.16	649.74	541.45	541.45	649.74	433.16	433.16	649.74
Education	599.76	599.76	899.64	749.7	749.7	899.64	599.76	599.76	899.64
Occupancy	c1l	c1m	c1h	c2l	c2m	c2h	urml	urmm	-
Residential	333.2	333.2	499.8	416.5	416.5	499.8	249.9	249.9	-
Commercial	333.2	333.2	499.8	416.5	416.5	499.8	249.9	249.9	-
Hospital	666.4	666.4	999.6	833	833	999.6	499.8	499.8	-
Repair service	333.2	333.2	499.8	416.5	416.5	499.8	249.9	249.9	-
Government	433.16	433.16	649.74	541.45	541.45	649.74	324.87	324.87	-
Education	599.76	599.76	899.64	749.7	749.7	899.64	449.82	449.82	-

3. Definition of Seismic Loss Scenario for Tehran

Generally, risk is defined as the expected physical damage and the resulting economic losses that are computed from the convolution of probability of occurrence of hazardous events and the vulnerability of the elements exposed to certain hazard [8]. According to the McGuire the seismic risk entails a set of events (earthquakes likely to happen), the associated effects (damage and loss in the broadest sense), and the associated probabilities of occurrence over a defined period of time [9]. Thus, the seismic risk can be expressed as the combination of seismic hazard, exposure, vulnerability, and assets involved [8]. Earthquakes may cause huge economic losses, the majority of which is contributed to the structural damages; however, the non-structural damages can impose considerable losses, especially, in industrial and hospital occupancy classes. It is worth pointing out that there are other sources causing economic losses after occurrence of earthquake, such as the debris collection. Since, the calculation of latter losses needs specific information related to the quality of roads and landfill distances, in this paper, we have focused only on structural losses.

3.1. Damage and Loss Assessment Method and Applied Software

In general, two approaches are available to estimate the earthquake damage suffered by a certain building. Traditional approach uses empirical parameters, such as macro seismic intensity or peak ground acceleration, to represent ground motion, whereas the more recent analytical method employs the entire response spectra, preferably, in the spectral acceleration–spectral displacement domain [10]. The capacity spectrum method has been applied to compute iteratively the inelastic spectral lateral displacement demand S_d, which is a measure of damage extent. In order to estimate the possible damage to the building stock of Tehran, the analytical risk and loss assessment tool SELENA has been applied [6]. In SELENA, three user-selectable methods are incorporated to compute the damage: the traditional capacity spectrum method proposed in ATC-40 [11], a recent modification called the modified acceleration-displacement response spectra (MADRS) method, and the improved displacement coefficient method I-DCM [12]. In the present study, we select the MADRS procedure. As mentioned above in this study we manipulated 17 types of HAZUS buildings. Capacity curves of these buildings are showed in Fig. 6.

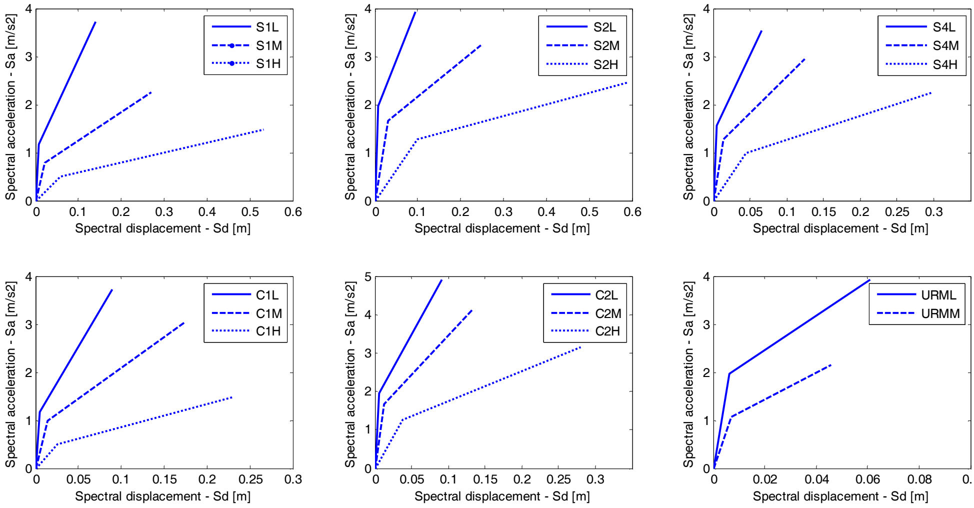

Fig. 6. Capacity Curves for selected model building types in the city of Tehran

The probability of being in or exceeding a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the spectral displacement, the probability of being in or exceeding a damage state, is modeled as:

$$P\left[ds \mid S_d\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \qquad (1)$$

Where:

$\bar{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of the damage state, ds, β_{ds} is the standard deviation of the natural logarithm of spectral displacement of damage state, ds, and Φ is the standard normal cumulative distribution function. Refer to HAZUS-MH technical manual to get Coefficients [7]. Probability of each damage level could be obtained from fragility curve. In Fig. 7 a typical fragility curve has been illustrated.

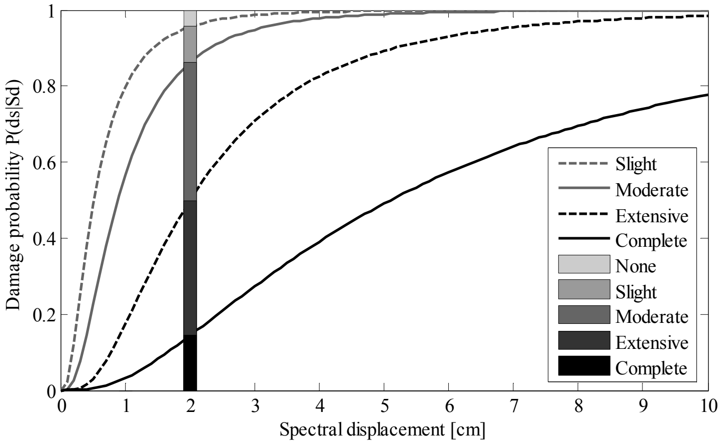

Fig. 7. Typical fragility curve and Damage probability

3.2. Probabilistic Earthquake Scenarios for Tehran

In this article, an evaluation of the seismic risk of Tehran is provided. There are several major faults surrounding Tehran, each of which has caused at least one severe earthquake. These faults have the potential to generate high-magnitude ground motions. Having a review of seismic risk of Tehran, we can conclude that we cannot choose a specific fault for subsequent steps of our study, so, a probabilistic scheme is used. According to the Iranian Code of Practice for Seismic Resistant Design of Buildings [2], Tehran is situated in a region with high seismic risk in Iran (Fig. 8).

3.3. Probabilistic seismic hazard parameters of Tehran

According to Iranian Code of Practice for Seismic Resistant Design of Buildings [2], the peak ground acceleration proposed for seismic design of structures in Tehran as a high-risk region is 0.35g. The methodology characterizes ground shaking using a standardized response spectrum shape as given in IBC-2006[13], which consists of four parts: PGA, a region constant spectral acceleration at periods from zero seconds to T_{AV}, a region of constant spectral velocity between periods from T_{AV} to T_{VD}; and a region of constatnt spectral displacement for periods of T_{VD} and beyond. In general, the elastic design spectrum $Sa(T)$ is defined by the following equations:

$$Sa(T) = Sa_{0.3}(0.4 + 0.6\frac{T}{T_A}) \qquad T < T_A \qquad (2)$$

$$Sa(T) = Sa_{0.3} \qquad T_A < T < T_{AV} \qquad (3)$$

$$Sa(T) = \frac{Sa_{1.0}}{T} \qquad T_{AV} < T < T_{VD} \qquad (4)$$

$$Sa(T) = \frac{Sa_{1.0}T_{VD}}{T^2} \qquad T_{VD} < T < 10s \qquad (5)$$

The period T_{AV} is based on the intersection of the region of constant spectral acceleration and constant spectral velocity and its value varies depending on the values of spectral acceleration that define these two intersecting regions:

$$T_{AV} = \frac{Sa_{1.0}}{Sa_{0.3}} \tag{6}$$

The period T_A representing the left corner period of the spectral plateau can be determined as follows:

$$T_A = 0.2T_{AV} = 0.2\left(\frac{Sa_{1.0}}{Sa_{0.3}}\right) \tag{7}$$

The constant spectral displacement region has spectral acceleration proportional to $1/T^2$ and is anchored to the spectral acceleration value at the period T_{AV}, where constant spectral velocity transitions to constant spectral displacement. The period T_{VD} is based on the reciprocal of the corner frequency f_c, which is proportional to stress drop and seismic moment.

$$T_{VD} = \frac{1}{f_c} \tag{8}$$

Where, f_c is the corner frequency.

The response spectrum which is usually in terms of Sa versus T is converted to Sa versus Sd. By definition, the values of Sd are calculated from the following formula.

$$Sd = g\left(\frac{T}{2\pi}\right)^2 Sa \tag{9}$$

Equation (9) gives the spectral displacement.

$$\text{Sa} = \text{A}\times\text{B} \tag{10}$$

Where:

A = design basis acceleration over bedrock (suggested value is 0.35g for the entire Tehran region)

B = the response factor representing both the amplifying effects of soil deposit and the structural response, simultaneously. Soil type is determined using the average shear wave velocity map presented in Fig. 2 [5]. Spectral accelerations for city of Tehran for four different soil types are presented in Fig. 9.

As it is obvious in Fig. 10, there is an acceptable agreement between the results of Iranian Code of Practice for Seismic Resistant Design of Buildings [2] and those of IBC-2006.

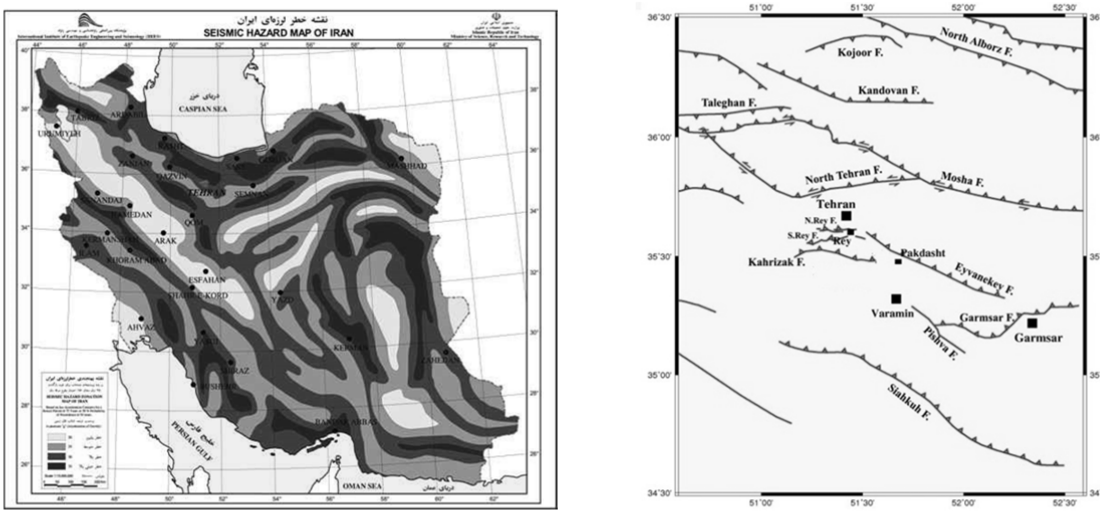

Fig. 8. Left: Iran's probabilistic seismic hazard map [2], Right: distribution of Tehran's faults [4]

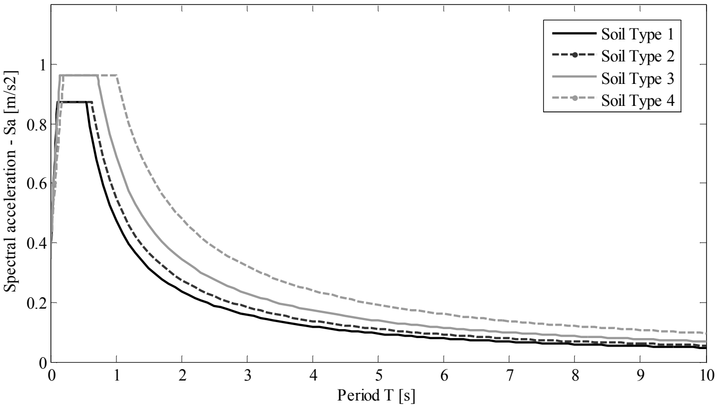

Fig. 9. Spectral acceleration of four soil types

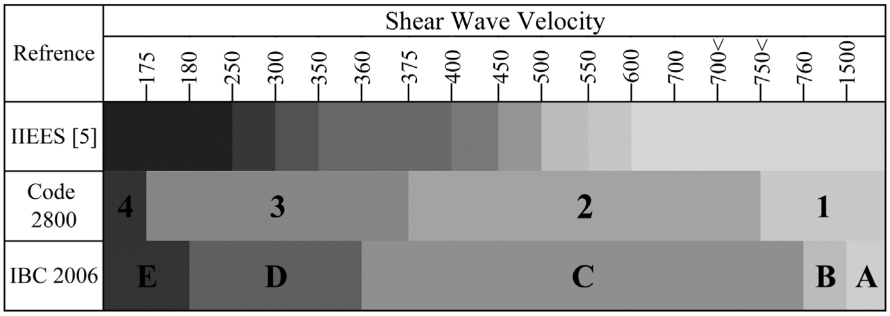

Fig. 10. Shear wave velocity domain using three references

4. Probabilistic Damage Scenario

4.1. Introduction of a Function Describing Building Damageability

Since damage estimates are provided as disaggregated numbers for distinct damage states (in this paper: slight, moderate, extensive, and complete), a one-to-one comparison of damage results is not easy to visualize . Consequently, damage and loss estimates are represented by total economic loss as well as mean damage ratio. Both parameters allow a one-to-one comparison between the results.

MDR can be computed for a certain area and building typology. Several MDRs can be defined for different purposes. In this study we calculated three types of MDR which are according below:

4.1.1. MDR for each geounit and all building types:

$$MDR_i = \frac{\sum_{k=1}^{mbt} DR_S^k N_{Si}^k + DR_M^k N_{Mi}^k + DR_E^k N_{Ei}^k + DR_C^k N_{Ci}^k}{N_{Ti}} \quad (11)$$

where DR_j^k: is the damage ratio of the model building type k corresponding the damage state j where $j = S$ for slight, M for moderate, E for extensive and C for complete. N_{ji}^k : is the damaged built area corresponding to the damage state j (S, M, E, C) for the model building type k at the geounit$i$. N_{Ti} is the total built area at the geounit i. for all the model building types $i = 1, \dots, mbt$.

This parameter helps us to compare different region in one city, and to determine which of regions must be in the top priority of rehabilitation process.

4.1.2 MDR for each model building types and all regions:

$$MDR^k = \frac{\sum_{i=1}^{geounit} DR_S^k N_{Si}^k + DR_M^k N_{Mi}^k + DR_E^k N_{Ei}^k + DR_C^k N_{Ci}^k}{N_T^k} \quad (12)$$

where N_T^k is the total built area for the model building type k and added to all the geounits i=1,…, geounits. Other parameters are according the above equation.

One of the criteria of city extension (both horizontally and vertically) is considering of its seismic vulnerability. This parameter demonstrates that between two years of study whether specific kind of structure has been built in less prone to earthquake area or not. Meanwhile, it can helps to authorities to determine the critical type of building for rehabilitation.

4.1.3. MDR for all model building type and all geounits:

$$MDR = \frac{\sum_{k=1}^{mbt} \sum_{i=1}^{geounit} DR_S^k N_{Si}^k + DR_M^k N_{Mi}^k + DR_E^k N_{Ei}^k + DR_C^k N_{Ci}^k}{N_T} \quad (13)$$

This parameter which is only one number to the whole city, demonstrates the mean damage ratio of entire city. It could be useful to compare to different city; or one city in different years to demonstrate whether the rehabilitation policies would be affective or not.

4.2. Probability of Structural Damages

The Number and type of casualties as well as MDR have changed in each region from 1996 to 2006. Looking into the damage probability of any structure in each soil type can help us to understand the reasons of these changes. Soil types used in this study are obtained according to Iranian Code of Practice for Seismic Resistant Design of Buildings. Levels of damage probability of structures in different soil types are shown in Fig. 11. In this Fig. first, second, third, and forth column of each building type are belonged to soil type 1, 2, 3, and 4, respectively.

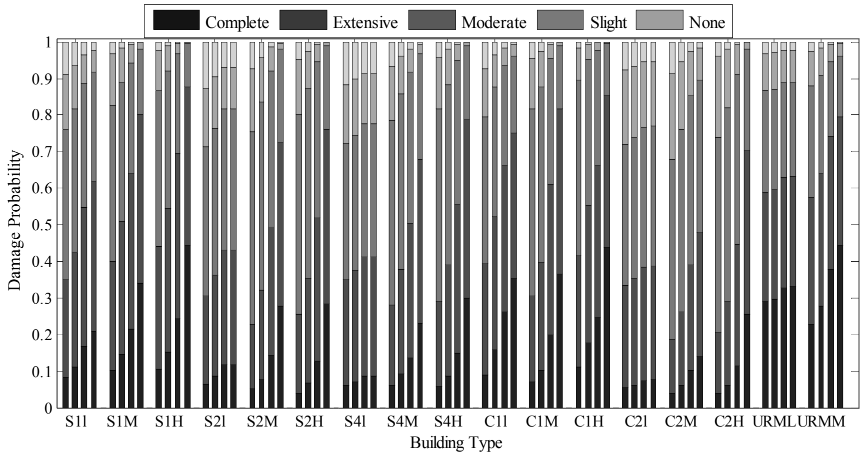

Fig. 11. Damage probability for structures in different soil types

4.3. Casualty Estimation for Tehran in 1996 and 2006

Because of the lack of information indicating the population of non-residential occupancy classes, in this study, we just calculate the 2:00 a.m. casualties, the results of which are mainly influenced by the selection of residential occupancy class. The casualties are classified based on HAZUS-MH category. The output of the module consists of the casualty breakdown by injury severity levels. Injury severity level 1 is used for low injured and injury severity level 4 is used for instantaneously killed or mortally injured [7]. Since injury severity level of 1 and 2 can be mainly affected by non-structural damages, Fig. 12 only provides cumulative number of casualties which are belonged to injury severity level of 3 and 4. Table 4 presents total casualties computed for Tehran.

4.4. MDR for regions of Tehran in 1996 & 2006

Mean damage ratio in each region in 1996 and 2006 which are calculated through equation (11) are depicted in Fig. 13, and Fig. 14 , respectively.

4.5. MDR for Buildings of Tehran in 1996 & 2006

With reference to the Fig. 15, we can obtain mean damage ratio calculated for each type of building in Tehran (According to equation 12).

4.6. Monetary Loss due to Probable Earthquake in Tehran

A probable monetary loss due to the possible earthquake defined by Iranian Code of Practice for Seismic Resistant Design of Buildings [2] is presented in Fig. 16. Monetary loss has been computed for both 1996 and 2006 using the same currency unit.

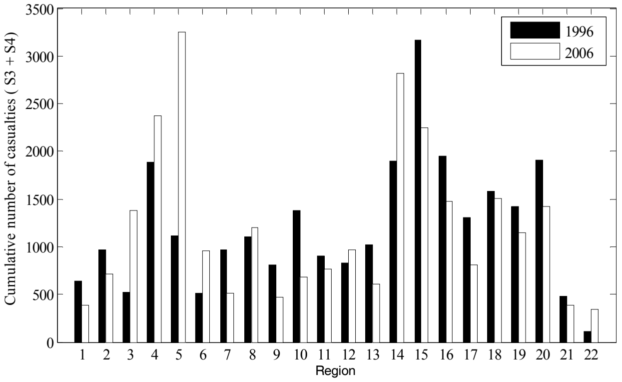

Fig. 12. Cumulative number of casualties (Severity3 + Severity4)

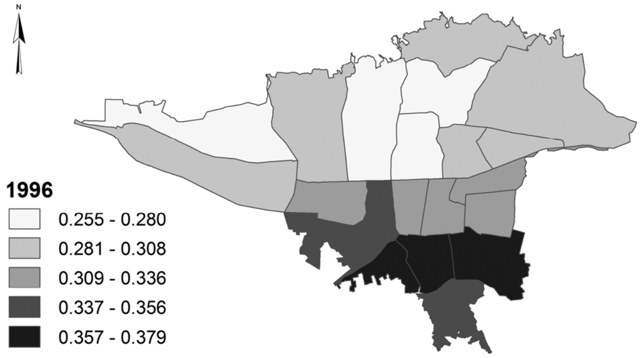

Fig. 13. MDR of different regions of Tehran in 1996

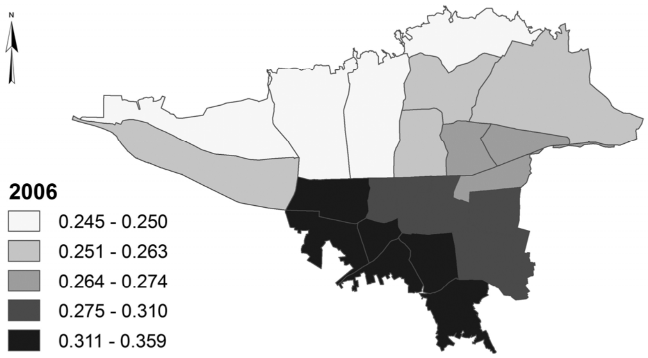

Fig. 14. MDR of different regions of Tehran in 2006

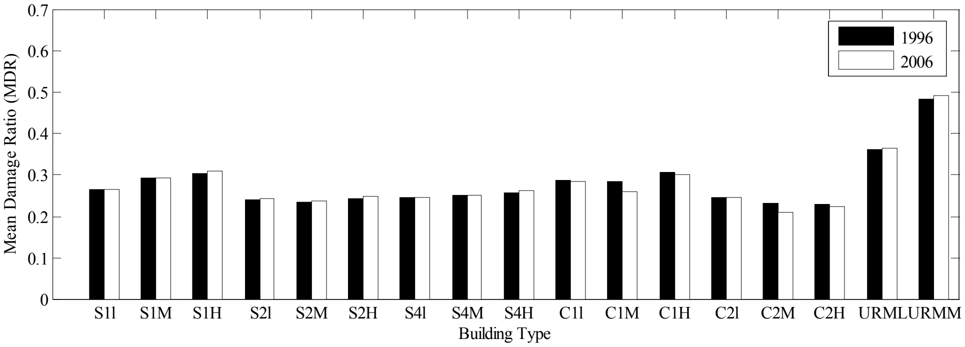

Fig. 15. MDR for each building type in Tehran computed for 1996 and 2006

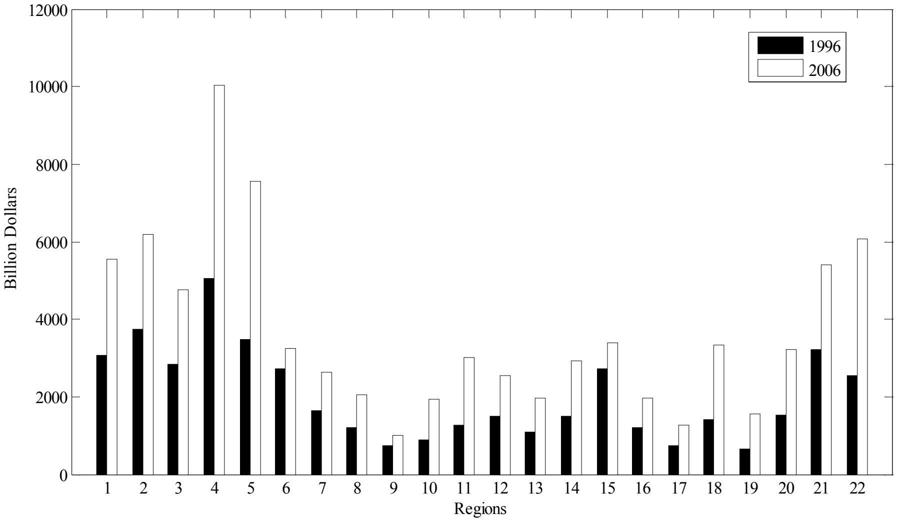

Fig. 16. monetary loss due to probable earthquake in Tehran in 1996 and 2006 (billions dollars)

Table 4. Cumulative number of casualties in Tehran

Census Year	Severity 1	Severity 2	Severity 3	Severity 4
1996	176971.7	54829.8	8056.2	15907
2006	171791	52855.1	7810.5	15423.3

5. Summary and Conclusions

860000 building stocks have been constructed in Tehran from 1996 to 2006. 150000 of these buildings are reconstruction of existing buildings and the rest are built newly [4]. In these ten years, Construction growth has been so rapid that the built area has almost doubled. The population has increased about one million; this growth in regions 1, 2, 4, and 5 has been high, while in regions 13, 16, 20, and 21, we observe negative growth. Many masonry buildings have been replaced by steel and concrete structures. Although a considerable growth in population has occurred in this period, the total casualties have been reduced. The reduction of casualties in regions 7, 9, 10, 11, 13, 15, 16, 17, 18, 19, 20, and 21 is more sensible. In these regions, more masonry buildings have been replaced with steel and concrete structures. Casualties have been increased in some regions. This growth is because of the concentration of populations in new medium and high-rise buildings. With reference to Fig. 11, it can be concluded that the seismic risk estimated for medium and high-rise buildings, the majority of which have been constructed in mentioned decade (1996-2006), is rather high. In addition, increased casualties mainly are in severity levels of 1 and 2, which are acceptable. Total MDR for entire of Tehran in this period has been decreased from 0.302739 in 1996 to 0.272859 in 2006. MDR of some building types has been increased, while that of others has been reduced. This is the result of change in the number of buildings and dominant building type in each region. To examine the masonry structures, we should note that the percentage of masonry structures in region 1 in 1996 is notable. On the other hand, the growth of construction in this region has been rapid. Therefore, since the type of soil in region 1 (type 1) causes less seismic risk, some of masonry structures, showing less damage, have been removed, and MDR for this type of buildings has been increased. MDR for concrete structures has been reduced due to the growth of concrete structures, mainly, in regions 4, 5, and 22. Seismic risk in these regions is less. The substitution of masonry structures with steel buildings and high percentage of this type of structures in middle and southern parts of Tehran have caused an increase in MDR for steel structures. It should be mentioned that in these parts of the city the type of soil increases the seismic risk.

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