Earthquake Risk Modeling using GIS for urban buildings, Case study: Tehran Municipality, District 3

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ABSTRACT

Inadequate preparedness against earthquakes burden for human settlements in seismic areas such as Iran would cause a lot of life and property damage. Several parameters affecting the seismic evaluation makes the appropriate model that has features such as a summary of the data and predicting the risks. This paper aims to use the physical parameters and programming the model-driven approach to provide location. In this study the most important factors contributing to the vulnerability of urban buildings due to the characteristics of the study area, which includes six indicators of internal and external factors in combination with the four indicators are taken into consideration for expressing the seismic vulnerability of the region. This applied study is with a quantitative method using survey techniques. In this regard, GIS Analytic Hierarchy Process is used. The results show that, as expected, the damage increases with increasing severity of earthquake. The vulnerability based on the number of buildings is located in regions 2, 3, 5, 4, 1 and 6.

INTRODUCTION

Many of the largest urban disaster in which many people are killed and injured, and many infrastructures are damaged by an earthquake and a hurricane (Dodman et al., 2013). Because of this, the most serious natural disaster is flood disaster and after that is the earthquake. Research centers of epidemiological studies estimate the mortality events in the last one hundred years of earthquake approximately 2/2 more than hurricanes, volcanic eruptions, landslides and avalanches. (Solano and Scaruzzo, 2013). The earthquake is known as the most common natural disaster, because many earthquakes are registered with different dimensions during decades which caused many damages. Due to the earthquakes registered, the rate of mortality is estimated approximately 800000 people (Rastivies et al., 2013). During 20th century, more than 1100 destructive earthquakes occurred in 75 countries around the world, and more than one million people were killed and caused many of damages for humanity. It is predicted that in twenty-first century at least 2 million people lost their lives and the damages caused by the earthquake also grow very fast (Nicholas, 2005). It is estimated that natural disasters in developing countries create losses twenty times higher than in developed countries (Western, 2004). Achieving sustainable development in countries prone to earthquake, it is possible to consider effective measures to reduce vulnerability to earthquake (Hashemi and Alesheikh, 2012).

Iran is also one of the regions that most seismic activation of the belt of the Alpine - Himalayan with many destructive earthquakes are recorded using scientific instruments and historical documents, this is due to its location in the folding area in three million kilometers of the Arabia-Eurasia (Gourabi and Yamani, 2011). Although Iran's population is 1% of the world population, losses due to the earthquake are about 6 percent of deaths worldwide (Carrion, 1384). According to a report by the United Nations Office of Planning in 2003, Iran rank is assigned first in the number of earthquakes with an intensity of 5.5 on the Richter scale in the one of the highest ratings in the area of earthquake damage (UNDP, 2004). In seismic zones like Iran, the seismic risk assessment in urban expansion is necessary and crucial. Urban development without considering the effect of the earthquake will lead to a humanitarian catastrophe, and in this situation, the city is greater, the greater the magnitude of the disaster.

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Seismic hazard assessment is of great importance, because inappropriate and unrealistic plans can cause huge losses of life and property and on the other hand, very careful design, higher reliability coefficients than necessary will impose unnecessary costs and wasted materials and labor. Reliable estimates of seismic hazard in the region requires knowledge and understanding of both the seismicity and ground motion during earthquakes (Ghosh and Mahajan, 2013). Many factors such as the use of inappropriate placement, construction, and improper construction and inadequate infrastructure, urban design, urban settlements are at increased risk (Tucker, 1994; Zetter and Hamza, 1998).

Assessing the seismic vulnerability of the required losses needs the estimation under the assumption of an earthquake at different levels and in different regions of the potential damage. The three municipalities in the region where are located several faults, are important. In addition, there are numerous factors such as construction in recent years, especially in high-rise buildings, retrofit of non-compliance with laws and regulations; high concentration of population in the old context, the Supreme peddling illegal and non-normative, using low-durable and non-durable materials, using unsustainable land for urban development particularly in the northwest region, the construction of the aqueduct route, the narrow streets in the old regions, and lack of proper plans to tackle financial crisis increased the region's vulnerability to earthquakes. Accordingly, the existence of earthquakes in region 3 is need to be researched in order to assess the damage caused by earthquakes and the distribution of the areas.

Therefore, this study pursues three goals: identifying the physical condition of Tehran District 3 against potential vulnerability to earthquakes, identification of areas vulnerable to earthquakes and providing a hierarchical model to reduce the vulnerability of different parts of a model to assess the physical vulnerability of the earthquake.

Area of study:

District 3 of Tehran Municipality is one of the 22 districts. This area is located in the northeast of Tehran. The area has 6 regions and 11 district with an area of 2945 ha (Hectares), respectively. This area is one of the largest urban areas of Tehran that is limited to the north by Shahid Chamran Highway, Shahid Modarres Highway and Sadr Highway and to the east to Pasdaran, part of Shariati Street and to the South to the Resalat highway and to the West to Shahid Chamran Highway (Sharan Consultant Engineers, 2006, 1)

The area 3 in the suburbs of Tehran Municipality aside the affecting faults is located in the vulnerability of Tehran such as the North Tehran fault and fault of Fasham – Masha, and to the south of Tehran the Ray fault, and Tehran Plain and its surrounding smaller faults within the Plain of Tehran such as Mahmudiye, Davudyyeh fault, Fault stagger down, and Kowsar and Shian fault. The faults in the development of seismic hazard in this area can aggravate the vulnerability.

Theoretical basis:

The literature review found that the assessment of natural hazards was performed at different scales in the world (Van Weston, 2006). However, it is one of the most controversial issues of vulnerability and risk issues that is done in the crisis field and its dimensions are still unknown (Alca'ntara - Ayala, 2008). Some studies that the author has concluded are as follows; Zangiabadi et al. analyzed the indicators of vulnerability to earthquakes in that study showed the vulnerability of buildings against earthquake risk is high in Isfahan. In assessing the vulnerability of urban structures and assessing their vulnerability form the earthquake using hierarchical analysis of urban vulnerability mapping and GIS can be achieved (ZANGIABADI and others, 2008).
Ahadnejad in his doctoral thesis entitled urban earthquake vulnerability using model (RISK-UE) and the method of AHP, they reached to the conclusion that the Tehran Municipality's area 3 and 2, respectively, have the highest and lowest vulnerability (Ahadnejad, 2009).

Also Giovinazzi et al. conducted the designing the scenarios and earthquakes using (RISK-UE) model to the region of Liguria in Italy vulnerability assessment. (Giovinazzi et al., 2006), Rashid et al. in their study first assessed the role of GIS and remote sensing, focused on modeling and predicting vulnerability and they concluded that Geographic Information System, a comprehensive database could have a major role in vulnerability modeling. (Rashed et al., 2003,6).

Seen from above, Urban vulnerability can be defined as the amount of the difference between urban communities' capacity to deal with the effects of natural hazards based on its location in the physical world (Spatial structure of the city), and social characteristics of communities (social structure of the city) defined (Ahadnejad, 2009, 43). The quantitative vulnerability assessment seeks to create a cumulative measure that is classified from zero (meaning free of vulnerability) to one (complete vulnerability). The scale cumulative sum of the various elements of vulnerability compared with steady state are dynamic aspects of the urban environment. These elements can be classified as follows:

Physical elements such as buildings, infrastructures, resources, ecosystems, and such economic factors such as land use, economic investment, and such social factors such as socio - economic status, morality, class, disability, age, and so on.

MATERIALS AND METHODS

Analytical approach and collecting data have been conducted through library and field studies. To analyze the data and evaluate the Analytic Hierarchy Process (AHP) and fuzzy logic is used to insert data into GIS software.

Multi-Criteria Decision Making (MCDM) is a powerful tool that is widely used for evaluating and ranking problems usually can be used for multiple conflicting criteria (Bilsel et al.2006). Multi-criteria decision making models generally divided into two categories: multi-objective models (MODM) and Multi-Attribute models (MADM). Many methods have been proposed for multi-criteria decision making. Analytical Hierarchy Process which was first proposed by Saati, is of the branches of multi-criteria decision making (MADM). This method is based on paired comparisons. Evaluation criteria and their weights must be determined according to their importance. This model involves the following steps; (Saati, 1990)

1) Create a hierarchy of problem
2) Paired comparison matrix determined by imposing judgments
3) Calculate the relative weights of the criteria and weighting options Final options
4) Check System Compatibility

The research for vulnerability assessment of 10 indicators used in the seismic data. Six indicators of internal factors, including: Type building material, old building, quality of construction, ground floor area, number of floors and the soil type and the four indicators of external factors including: Compatible land uses, directions Canal, close to the fault and width of streets that each of the following criteria are divided into internal and external factors. To calculate the weight of indexes and interference susceptibility factor for each of the indicators used in the software Expert Choice 2000. Total buildings assessed were 28,939 that their composition is shown in Table 1.

Discussion and Analysis:

In this study, factors and criteria and detailed criteria are shown in table 2. That their representation is used as a rating system and the analysis by the Expert Choice software was designed based on the results are shown in Figure 2.

Table 1: Examines the breakdown of plaque areas (writer)

<table>
<thead>
<tr>
<th>Area</th>
<th>Number</th>
<th>Area</th>
<th>Number</th>
<th>Area</th>
<th>Number</th>
<th>Area</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4000</td>
<td>2</td>
<td>6175</td>
<td>3</td>
<td>5921</td>
<td>4</td>
<td>4512</td>
</tr>
<tr>
<td>5</td>
<td>5818</td>
<td>6</td>
<td>2513</td>
<td>Total</td>
<td>28939</td>
<td></td>
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</tbody>
</table>

Discussion and Analysis:

In this study, factors and criteria and detailed criteria are shown in table 2. That their representation is used as a rating system and the analysis by the Expert Choice software was designed based on the results are shown in Figure 2.

Table 2: details the main criteria and quantitative measures (author)

<table>
<thead>
<tr>
<th>main criteria</th>
<th>Tiny criteria</th>
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<tbody>
<tr>
<td>Building Materials</td>
<td>Mud, brick and wood</td>
</tr>
<tr>
<td>Dating back building</td>
<td>Before 1350</td>
</tr>
<tr>
<td>Building quality</td>
<td>New construction</td>
</tr>
<tr>
<td>Compatibility with adjacent land uses</td>
<td>Completely incompatible</td>
</tr>
<tr>
<td>Surface area occupied</td>
<td>Less than 100 m²</td>
</tr>
<tr>
<td>Brick and Cement</td>
<td>1360-1351</td>
</tr>
<tr>
<td>Mantainable</td>
<td>3.2</td>
</tr>
<tr>
<td>Completely incompatible</td>
<td>Relatively incompatible</td>
</tr>
<tr>
<td>250 -100 m²</td>
<td>Relatively compatible</td>
</tr>
<tr>
<td>Brick and Iron</td>
<td>1370-1361</td>
</tr>
<tr>
<td>Destructive</td>
<td>5.4</td>
</tr>
<tr>
<td>Indifferent</td>
<td>Higher than 6</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>1380-1371</td>
</tr>
<tr>
<td>Steel structure</td>
<td>Higher than 6</td>
</tr>
<tr>
<td>After 1380</td>
<td></td>
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<td></td>
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</tbody>
</table>

Table 2: details the main criteria and quantitative measures (author)
Comparison of binary indicators show that, due to its importance in the construction of earthquake has achieved highest score. The recent earthquake experience has shown that type of building materials used in the construction of earthquake damage than other parameters is important. The more durable materials used in the construction of earthquake decreases vulnerability severity. After mapping the overall vulnerability index using AHP method was with three levels 6, 7 and 8 on Mrkaly scale modified calculated and applied using the model proposed by Milutinovic and Trendafiloski (Milutinovic and Trendafiloski, 2003: 65).

\[
\mu_D = 2.5 \left[ 1 + \tanh \left( \frac{I - 19.1}{22} \right) \right]
\]

\[\mu_D = \text{average degree of damage} \]
\[I = \text{Indicator of the intensity of an earthquake based on the modified Mrkaly} \]
\[\bar{I} = \text{the amount resulting from applying the AHP and attribute vulnerability}. \]

The results of map 1 shows the vulnerability of 6 regional-scale corrected Mrkaly that the vulnerability of buildings is low, very low and moderate in 2, 3 and 5 municipalities areas which are more metal skeleton, then the most resistant structures in earthquake of zone 3 of Tehran are in areas 2, 3 and 5, respectively. 14.73% of the buildings in the area are in the range of high vulnerability, most of them are in zone 3 in the neighborhood of Rostamabad, and 5 municipality in the region are in the neighborhood of Chalhorz which has the traditional context. Buildings that are highly vulnerable were the final regional headquarters, 0.21 percent are the majority of mud brick structures have been scattered in the neighborhood of Vanak and Zargandeh.

The regional vulnerability to earthquake in the study area with the intensity of modified 6 Mrkaly showed that 53/88% of buildings in earthquake intensity with 6 Mrkaly faced with very little vulnerability. Most of the buildings in the 2 area of municipality in the eastern neighborhood of Zargandeh, in 3 municipality in the North-West area of zone 5 is optional and municipality in the northeastern neighborhood of Ehteshamiyeh are respectively 11.39, 10.09 and 10.82 percent vulnerability. 45.81% of the buildings have moderate and low vulnerability that the maximum number of them are located in zone 2 area in the North – West in neighborhood of Amani. Map 1 shows the details of their distribution.

Map 1: damage to buildings in the district 3 of Tehran in the earthquake of intensity 6 Mrkaly amended (the author)

Map 2 shows that the seismic intensity of 6 to 7 Mrkaly, degradation is very high, so that 43.46 percent of the building with three floors of the vulnerability are of very low, low and moderate, the frequency of buildings is due to resistant materials of construction and standards prevailing in the country, including the 2800 code. However, compared to the previous state shows a decrease in resistance state. Most of the buildings are located in three areas 2, 3 and 5 municipalities. The most vulnerable area in the region 2 of Zargandeh and Vanak, as already mentioned, very narrow streets and rural textured materials, mud brick and buildings of brick and cement can be observed.
Map. 2: Damage to buildings in the district 3 of Tehran in the earthquake of intensity 7 Merkaly amended
(author)

8 Merkaly severity of the vulnerability curve shows an upward increase in the magnitude of the complete
destruction. Accordingly, when faced with an earthquake of 8 Merkaly any of the six areas of study will not be
safe of the damage but the damage to the order drops of 2, 3, 5, 4, 1, and 6. 22/87% of the buildings in the area
affected would be low or negligible that most of these business units or buildings, renovated buildings that are
mostly metal structures, and engineering principles and standards are observed in the Code of 2800 in the
construction of these structures. Map 3 shows the details.

Map. 3: The damage to buildings in the district 3 of Tehran in the earthquake of intensity 8 Merkaly amended
(author)

Conclusion:
As expected casualty rate also increased with increasing severity of the earthquake. But the scale of the
damage zone 8 does not protect against earthquake damage, it was something that was not understood at first
glance, the result of this study shows this. Also, due to the neighborhood of Zargandeh and Vanak even with
lower intensity of earthquake damage was much greater than in other places, it seems that certain policies
should be taken to remedy the situation of their buildings and the priorities to be correct. According to Figure 2,
it is seen that the seismic intensity scale in each case is the same as low damage with little tolerance for
intermediate situation is also applicable. However, the results indicate that behavior of structures against
different intensities of the vulnerability of low, high and complete destruction of the reasons could be different
in the subject of future studies.
In the current study, it was found that the obtained data to analyze the vulnerability of the infrastructure is not available or has not been collected. Therefore, require access to a complete database of vulnerabilities, including bridges, roads, hospitals, gas, power, water, telecommunications and industrial centers, and non-hazardous chemical that is needed in this area will be provided by the organizations and recorded in a centralized database.

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