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Evaluation of Seismic Vulnerability of Masonry Buildings without Ties Using the RISK-UE Method, Case Study of Kermanshah City

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ABSTRACT: Investigating the seismic vulnerability of masonry buildings without either horizontal or vertical ties, are important due to their number of usage more specifically in old parts of cities. Kermanshah, as a cultural center of west of Iran and 9th most populated city of Iran, hosts large number of masonry buildings. Besides, the city is located in the seismically active region of Zagros. Hence, it is crucial for urban planning of the city to study the seismic vulnerability of these buildings. Three major types of masonry buildings, which are brick walls with steel beam, brick walls with wooden beam, and adobe buildings are identified and their seismic vulnerabilities are evaluated using the RISK-UE method. The vulnerability of these buildings in terms of damage level as well as the human vulnerability rate estimated from the severity of the demolition of these buildings for each area of the city, assuming that 80% of the people are in the roofed places during the earthquake scenarios. The results show that under the earthquake scenario with return period of 475 years, more than 12% of brick walls with wooden beam, 11% of brick walls with steel beam, and 29% of adobe buildings, may experience severe structural damage or complete destruction. Furthermore, under the earthquake scenario with return period of 2475 years, the level of severe structural damage or complete destruction is expected for more than 42% of brick walls with wooden beam, 39% of brick walls with steel beam, and 66% of adobe buildings.

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1- Introduction

Earthquakes as a natural activity of earth mostly cause risky and harmful events for the human societies, which are not adequately prepared and properly aware of facing its occurrence. Experiences of past earthquakes all over the world have proved that unawareness and unpreparedness against earthquakes can result into exaggerated social and economic effects more specifically at more populated cities. Clearly, governments should know that in a seismically active region, the earthquake events are inevitable but saving more lives and economy is the only possible plan by applying risk and vulnerability reduction methods. Statistics show that in 20th century more than 1100 destructive earthquakes have happened across the globe and more than 1.5 million people have lost their lives duly, which the 90 percent of life loss was because of collapse of unsafe and none-engineered buildings [1]. Estimation of the expected damage probability of buildings in a region due to an earthquake scenario is known as seismic vulnerability assessment that defines the damage level of buildings and human life losses and injuries in a standard framework [2].

Earthquake engineering has been grown throughout observation of actual response of structures and application of engineering to resist elaborated earthquake force. Though, past events have come with lessons and recent knowledge and technologies are available to simulate possible situations in future. Seismic design codes and regulations are evolving to practice safe and engineering construction. However, the majority of the populated cities host none-engineered buildings with various usage, which were constructed with improper materials. The masonry buildings, which use masonry walls for bearing vertical loads, are always prone to severe damage or collapse in earthquakes. Therefore, investigating the seismic vulnerability of masonry buildings without either horizontal or vertical ties, are important. These buildings usually were built in a specific era and cover parts of the city generally called as deteriorated regions.

Recent investigations present examples of evaluation of the seismic vulnerability of the urban area using spatial multicriteria analysis and Geographical Information System (GIS). The seismic vulnerability of Los Angles was investigated by applying fuzzy rules [3]. Vulnerability index and capacity spectrum method were used to study Barcelona by RISK-UE model [1]. Two cities of Switzerland also were studied by RISK-UE model and capacity spectrum method to express the damage level of each type of structure that was used to be illustrated by GIS maps [4]. Such investigations have been started as early as the 21st century by the seismic micro-zonation project of greater Tehran [5], providing the fragility curves of different types of common structures in Iran. Similarly, the seismic vulnerability of various types of structures of Qazvin was assessed by modified qualitative ARYA method [6], which showed that the majority of

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masonry buildings and some steel and concrete frame type structures may suffer severe damage in moderate to severe earthquakes. Furthermore, seismic vulnerability of the residential buildings of Isfahan was investigated using both qualitative and quantitative specifications of the buildings [7]. Analytical Hierarchy Process (AHP), was used along with GIS implementation to map seismic vulnerability of various regions of Zanjan [8], which clearly showed deteriorated region of the city with the majority of masonry buildings is highly vulnerable to earthquake scenario, meanwhile the newly built structures complying the seismic code of Iran receives much less damage. More recently, fuzzy decision making methods like TOPSIS was used to evaluate the residential buildings of District No.9 of Tehran [9]. They used fuzzy rules to make dealing with vagueness of data possible.

In the past decade, a project sponsored by World Bank was done with the aim of seismic risk reduction and reconstruction of four cities in west of Iran; Kermanshah, Qazvin, Zanjan, and Hamadan [10]. In this project the RISK-UE method was followed and a GIS based software called ARMAGEDOM was applied to demonstrate vulnerability of residential buildings as well as historical and important buildings like hospitals, fire stations and life lines. The current study, focuses on the evaluation of seismic vulnerability of masonry buildings without either horizontal or vertical ties in Kermanshah with the first level of RISK-UE method. The same GIS based software is applied to update information layers and vulnerability assessment analyses. The World Bank project [10], was using statistics of Statistical Center of Iran (SCI), collected in 1375 in which the city was divided into 281 zones. The current study, is updated with statistics of SCI of 1390 [11], in which the number of zones is increased to 575 and municipal district of the city is increased to 8. Furthermore, this study covers the gaps of data in the statistics of first project [10], by modeling whole city and updating the building information to 1395 and population data to 1390. It is worth noting that, the sources of data are; SCI, Kermanshah Department of Housing and Urban Development (KDHUD), Kermanshah Construction Engineering Organization (KCEO), as well as field observations.

2- Kermanshah and its Seismicity

Kermanshah is the capital for the Kermanshah province located in western borders of Iran. The city has clear roots in the various historic era. The current landscape of the city can be clearly divided into historic and cultural texture and the modern era. The majority of the historic and cultural monuments dates back to end of 19th century of Qajar dynasty. The modern era mostly is rebuilt after Iran-Iraq war that it had been harshly damaged. According to the census of 1390, Kermanshah has population of 836058 persons, who are living in 93.4 square kilometers [11]. This will rank Kermanshah as the ninth populated city of the country and the most populated city in the west of Iran.

In terms of seismotectonics, Kermanshah is located in North-western seismotectonic province of Iran plateau that contains four main fault zones including; Main Zagros Reverse Fault (MZRF), High Zagros Fault (HZF), Mountain Front Fault (MFF), and Zagros Foredeep Fault (ZFF). Kermanshah has experienced significant earthquakes of 20th century like; Farsinaj 1957 (1336), Ms=7.1, mb=6.5, Nahavand 1958, Mw=6.6, and Karkhaneh 1963 (1342), Mw=5.8 all three caused by MZRF as well as the recent earthquake of 12th Nov. 2017 (21st Aban 1396) Sarpole-Zahab Mw=7.3 that was caused by MFF.

3- Seismic Vulnerability Assessment by RISK-UE Method

The first level of seismic vulnerability assessment by RISK-UE method is a qualitative approach that was first introduced by [12]. This method is based on the damage probability matrix, which is expressed by statistical correlation of European Macro-seismic intensity (EMS-98) and the apparent damage levels that were observed in past events in the region. In this way, different specifications of a building type including; height, Irregularity in plan, relative position of buildings to each other are studied and then a vulnerability index (Vi), is assigned to that type of building. The vulnerability index will define the most possible damage category. Thus, the vulnerability index varies between zero (i.e. invulnerable), and unit (i.e. severely vulnerable) [13]. According to EMS-98 five damage levels are defined based on the post-earthquake observations that are presented in Table 1.

As the damage levels to the buildings and constructions are defined then RISK-UE method defines the five levels of human injuries that are presented in Table 2.

Table 1. Definition of damage levels in EMS-98 [10]

D0	D1	D2	D3	D4	D4	D5
No Damage	Slight	Moderate	Heavy	Very Heavy	Very Heavy	Collapse

Table 2. Definition of human injury levels in RISK-UE [10]

Damage Grade	P0	P1	P2	P3	P4	SA
Damage	Unharmed	Lightly injured	Badly injured	Buried under rubble	Deceased	Homeless

4- Identification of building types

Samples of buildings that are studied are presented in Figure 1 and each category is identified as followings.

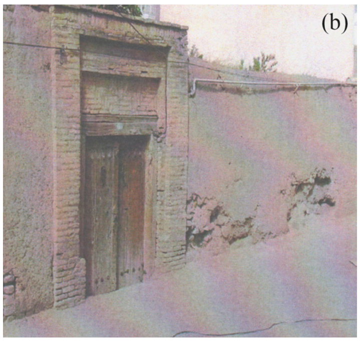

Figure 1. Samples of three categories of masonry buildings in Kermanshah, (a) brick walls with wooden beam, (b) adobe buildings, (c) brick walls with steel beam

4- 1- Brick wall with wooden beam (M1)

This type known as (M1), is formed of unreinforced brick walls, which the roof load in transferred by wooden beams to the walls. Generally, the seismic vulnerability is affected by situation, size, and numbers of openings in walls. Large openings, small columns at corners, and thin inner walls compared with the area of each room will increase the vulnerability of the building. In such buildings, roofs even flat or gable, do not form rigid diaphragms to be capable of uniformly distributing the horizontal earthquake force to the load bearing walls. Mortar or Lime mortar is used to bind the bricks in the walls that is weaker than cement mortars. These buildings either have no foundation or just weakly bonded bricks or stones are used as foundation. These buildings are mostly one or two stories and more than 20 years old.

4- 2- Brick wall with steel beam (M2)

This type known as (M2), is formed of unreinforced brick walls, which the roof load in transferred by steel beams to the load bearing walls. The steel beam roofs are consist of steel profiles laid parallel to each other with specific distance and in between the beams, the bricks are placed to produce slight arched shape. Generally, the seismic vulnerability is affected by situation, size, and numbers of openings in walls. The main factor in increasing the vulnerability of these buildings are roofs that has weak performance during earthquake and are not able to transfer the earthquake loads properly to walls. Furthermore, the mortar used in these buildings is relatively weak and has lower shear strength than standard values. These buildings either have no foundation or just weakly bonded bricks or stones and sometimes unreinforced concrete are used as foundation. Other elements like chimney and large pipes, which cause large gaps in load bearing walls will also weaken them against earthquakes.

4- 3- Adobe building (A1)

Adobe buildings use clay bricks, which their seismic strength are variable due to their various methods of construction. Walls that are built with layers of clay and without using rigid bricks are too weak. Adobe buildings with wooden frames have shown better lateral resistance. Adobe buildings have one or two stories and mostly are more than 30 years old.

5- Identification of fragility curves

The first level of RISK-UE uses fragility curves to evaluate the vulnerability of building. The fragility curve is defined as the relation between seismic risk parameter i.e. macro-seismic intensity (I), and damage i.e. the average damage level (μ_D). It will identify the probable behavior of a building by a single vulnerability index. The average damage level (μ_D), is evaluated by averaging over the damage level of a group of buildings in the same category. It is worth noting that the average damage level is defined as a continuous parameter describing the level of probable damage to a group of buildings in various macro-seismic intensities. Figure 2, presents the standard fragility curves of Risk-UE method for various vulnerability indices.

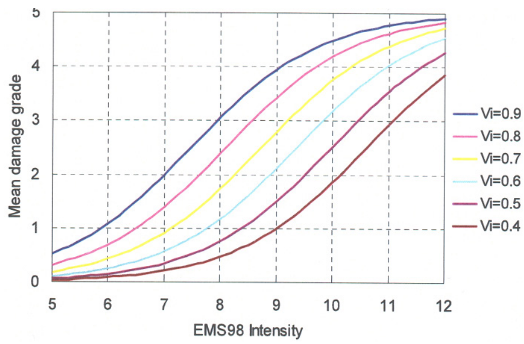

Figure 2. Average damage grade in terms of EMS-98 for various vulnerability indices used in RISK-UE method [10]

The standard fragility curves are modified according to studies of [10] for the various building types in the region. Figures 3 to 5 represent the modified fragility curves for three masonry buildings (i.e. A1, M1, and M2), in the current study. Note that in Figure 5, two curves are presented, which distinguishes one or two stories (M2L), and more than three stories (M2M) buildings.

The vulnerability indices from RISK-UE method and buildings of Iran [10], are presented in Table 3 for the three categories of masonry buildings without horizontal and vertical ties. In order to be on the safe side, the maximum value of the vulnerability index from RISK-UE and buildings of Iran is considered in this study.

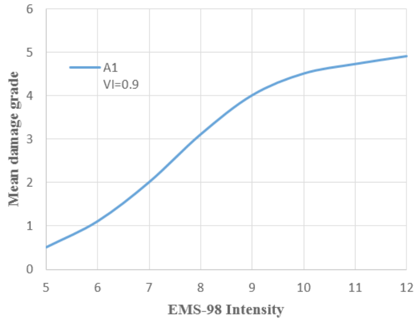

Figure 3. Average damage grade in terms of EMS-98 for adobe buildings (A1) [10]

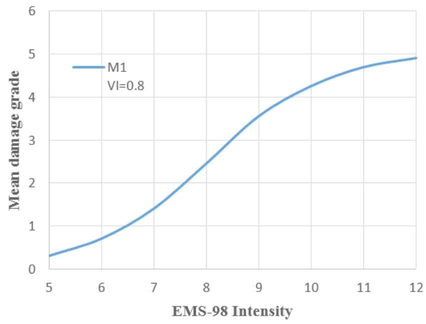

Figure 4. Average damage grade in terms of EMS-98 for brick wall and wooden beam (M1) [10]

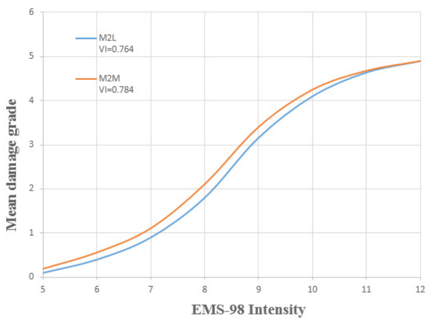

Figure 5. Average damage grade in terms of EMS-98 for brick wall and steel beam (M2) [10]

According to the vulnerability indices of Table 3, the brick wall and steel beam buildings (M2), have higher seismic vulnerability compared with brick wall with wooden beam and adobe buildings.

6- Population and building statistics

Required data are population and building statistics. For the population statistics, the SCI's census of 1390 [9], which was the latest national census by the date of this study is used. Census of 1390 divides Kermanshah city into 575 zones and provides detail information of building types, year of construction, number of residential units, location of the building and population of the residence in the level of city blocks. However, this statistics lack data for the number of stories for each building unit and to fulfill this field survey is carried out along with searching documents in the local municipalities and Kermanshah department of housing and urban development (KDHUD), Kermanshah construction engineering organization (KCEO). The survey is done on 100 buildings in each zone and resulted in; a) matching the data from various sources, b) verifying age distribution of buildings across the city by satellite photos. Table 4, presents the number of masonry buildings with their residential population that are considered in this study.

Table 3. Vulnerability index for the three masonry buildings of Kermanshah [10]

Building Type	Vulnerability index (V_i)	
	Current study	RISK-UE
M1	0.8	0.74
M2L	0.764	0.704
M2M	0.784	0.704
A1	0.9	0.84

Table 4. Population and the number of the masonry buildings in the current study

Building Type	A1	M1	M2	
			M2L	M2M
No. of buildings	1960	14228	54516	21911
Population	1306	45747	161054	95887

Masonry buildings of three types of this study are not uniformly distributed across the city. The adobe buildings and brick wall with wooden beam are mostly located in the central and historic texture of Kermanshah, but the brick wall with steel beam buildings are found relatively in all zones. Figure 6, presents the distribution of the three masonry buildings that are studied in the Kermanshah. Colors in Figure 6, from red to yellow, green, blue, and white show decreasing in the number of buildings in a zone.

Two earthquake scenarios are considered in this study, the earthquakes with return period of 475 years and 2475 years, the former corresponds to the Design Base Earthquake (DBE), and the latter corresponds to Maximum Credible Earthquake (MCE). The horizontal peak acceleration of each scenario at ground surface that includes the local geotechnical site effects, are presented in Figure 7 [10].

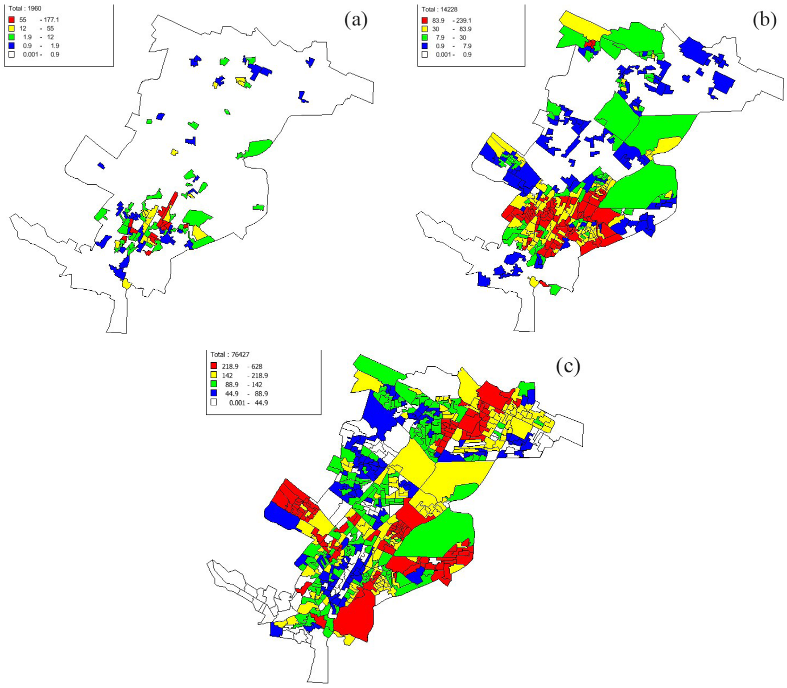

Figure 6. Distribution and number of masonry buildings in Kermanshah, (a) M1, (b) A1, (c) M2

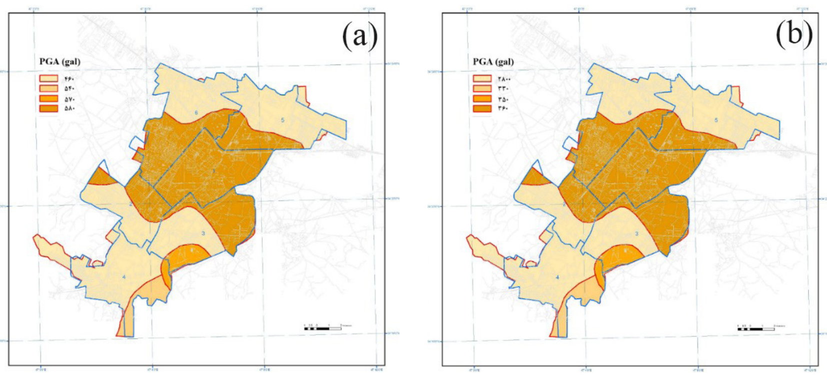

Figure 7. GIS map for PGA at ground surface in Kermanshah, (a) MCE, (b) DBE, [10]

7- Discussions on the results

The seismic vulnerability of masonry buildings of Figure 6, is evaluated with two earthquake scenarios, which are considering the seismic hazard as well as the Geotechnical site effects (Figure 7), by means of the GIS based software of ARMAGEDOM. The outputs of vulnerability assessments are presented and discussed in two sections; the seismic vulnerability of the buildings and the people.

7- 1- Seismic vulnerability of buildings

Table 1, presented the damage levels of buildings according to RISK-UE method in five levels. Sever physical damage to the buildings corresponds to D4 and D5 levels. The damage level of D4 is described as important structural damage and very important nonstructural damage like sever failure of walls and slight failure of roofs. The damage level of D5 is described as very important structural damage or complete collapse of the building. Therefore, the damage levels of D4 and D5 demonstrate that very heavy damage or collapse of the buildings, which means it must be rebuild after the earthquakes. This is shown in Figures 8 to 11, for the masonry buildings under study for both DBE and MCE earthquake scenarios. The colored zones in Figures 8 to 11 demonstrate different percentage of damaged buildings. Red corresponds to the maximum percentage and white corresponds to the minimum percentage. It is worth noting that the colored zones must be interpreted by distribution of the locations of buildings i.e. Figure 6.

Figure 8, maps the (D4+D5) damage of the masonry buildings type M1. It is revealed from Figure 8a, that the maximum percentage of the damaged buildings is 54.6 to 57.3 percent in MCE scenario that is colored in red. The maximum percentage of the damaged buildings is 20.1 to 22.1 in DBE scenario as is shown in Figure 8b.

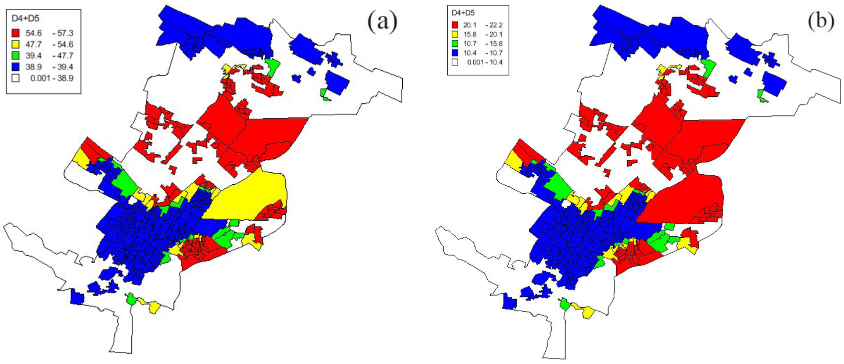

Figure 8. Percentage of damaged M1 buildings with level of D4+D5, (a) MCE, (b) DBE

Figure 9, maps the (D4+D5) damage of the masonry buildings type M2L. It is revealed from Figure 9a, that the maximum percentage of the damaged buildings is 46.2 to 47.9 percent in MCE scenario that is colored in red. The maximum percentage of the damaged buildings is 14.4 to 15.9 in DBE scenario as is shown in Figure 9b. Figure 10, maps the (D4+D5) damage of the masonry buildings type M2M. It is revealed from Figure 10a, that the maximum percentage of the damaged buildings is 51.5 to 53.1 percent in MCE scenario that is colored in red. The maximum percentage of the damaged buildings is 18.9 to 19.3 in DBE scenario as is shown in Figure 10b. Figure 11, maps the (D4+D5) damage of the masonry buildings type A1. It is revealed from Figure 11a, that the maximum percentage of the damaged buildings is 77.5 to 79.6 percent in MCE scenario that is colored in red. The maximum percentage of the damaged buildings is 42.2 to 45.7 in DBE scenario as is shown in Figure 11b.

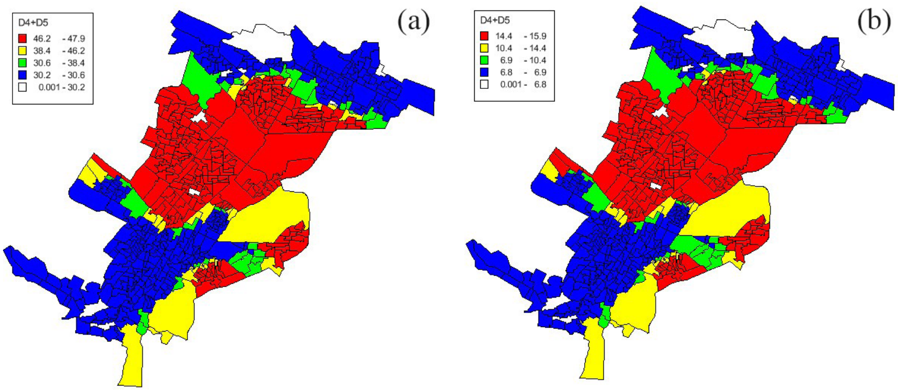

Figure 9. Percentage of damaged M2L buildings with level of D4+D5, (a) MCE, (b) DBE

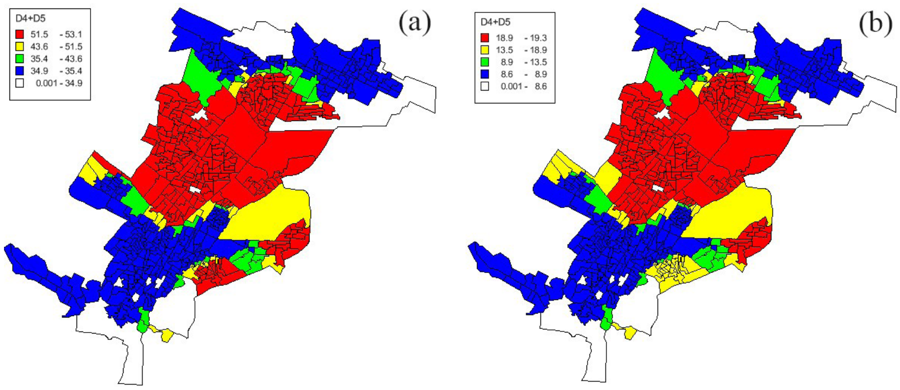

Figure 10. Percentage of damaged M2M buildings with level of D4+D5, (a) MCE, (b) DBE

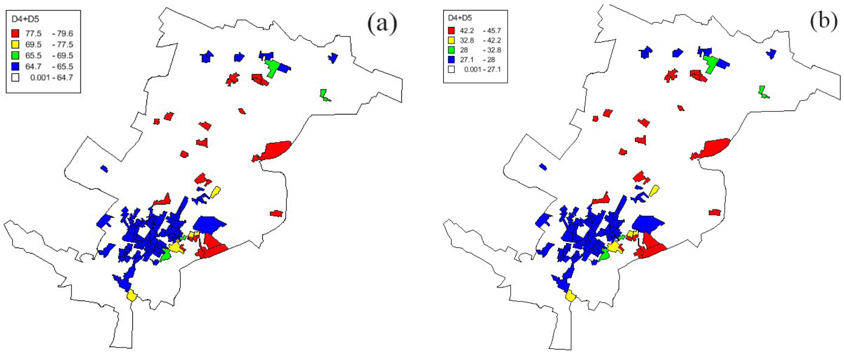

Figure 11. Percentage of damaged A1 buildings with level of D4+D5, (a) MCE, (b) DBE

Now it is possible to combine the results of the vulnerability analyses of Figures 8 to 11 with Figure 6, to find out the actual percentage of damaged buildings of each type at each scenario. Thereby, Figure 12 presents that out of total number of 14228 buildings of type M1, about 12 percent will experience D4 and D5 damage levels in DBE scenario and 42 percent will experience the same damage levels in MCE scenario. Similarly, out of total number of 54516 buildings of type M2L, 10.5 percent will experience D4 and D5 damage levels in DBE scenario and 37.5 percent will experience the same damage levels in MCE scenario. Out of total number of 21911 buildings of type M2M, about13.5 percent will experience D4 and D5 damage levels in DBE scenario and 43.5 percent will experience the same damage levels in MCE scenario. Finally, out of total number of 1960 buildings of type A1, about 29 percent will experience D4 and D5 damage levels in DBE scenario and about 66 percent will experience the same damage levels in MCE scenario.

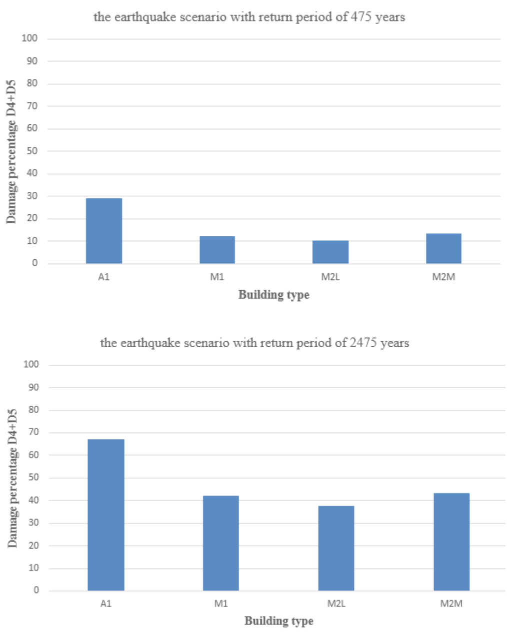

Figure 12. Percentage of damaged buildings with level of D4+D5, (a) DBE, (b) MCE

7- 2- Seismic vulnerability of People

When the direct damages to the buildings are found, consequently it is possible to evaluate the social impacts of the event and vulnerability of people. According to census of 1390 published by SCI 836058 people are resident in Kermanshah city, which out of them 303994 people i.e. about 36 percent are living in masonry buildings without any ties. The current study assumes that by the moment of the earthquake scenario 80 percent are inside these buildings, thus 243195 persons are affected by the event. In the followings, the number of injured people, the number of people who their lives are at risk, and the number of people who need shelters after the earthquake, are presented and discussed in Figures 13 to 15. Referring to Table 2, one defines the injured people as P1 and P2, people who their lives are at risk as P3 and P4, and homeless people as SA. The main purpose of such analysis is management of the crisis. It is crucial to know, if the available hospitals and health care centers are capable to serve the injured people? If the cemetery and related services can deal with the number of dead bodies? How many temporal house or shelters are required for the homeless people?

Figure 13 summarizes the number of injured people (P1+P2) in two earthquake scenarios of DBE and MCE. It is found from Figure 13a, that about 29600 persons suffer this level of injury in MCE scenario and the red colored zones are where the maximum injuries of 108 to 247 persons happens. Figure 13b represents, about 8957 persons suffer the P1+P2 level of injury with the maximum injuries at red colored zones as 33 to 77 persons during DBE scenario.

Figure 14 summarizes the number of people, who their lives are at risk (P3+P4), in two earthquake scenarios of DBE and MCE. It is found from Figure 14a, that about 7811 persons lose their lives in MCE scenario and the red colored zones are where the maximum death of 30 to 70 persons happens. Figure 14b represents, about 997 persons lose their lives, with the maximum death at red colored zones as 4 to 9 persons, in DBE scenario.

Figure 15 summarizes the number of homeless people (SA) in two earthquake scenarios of DBE and MCE. It is found from Figure 15a, that about 212174 persons need home in MCE scenario and the red colored zones are where the maximum number of homeless people of 664 to 1997 persons happens. Figure 15-b represents, about 115797 persons need home, with the maximum homeless at red colored zones as 412 to 962 persons, in DBE scenario.

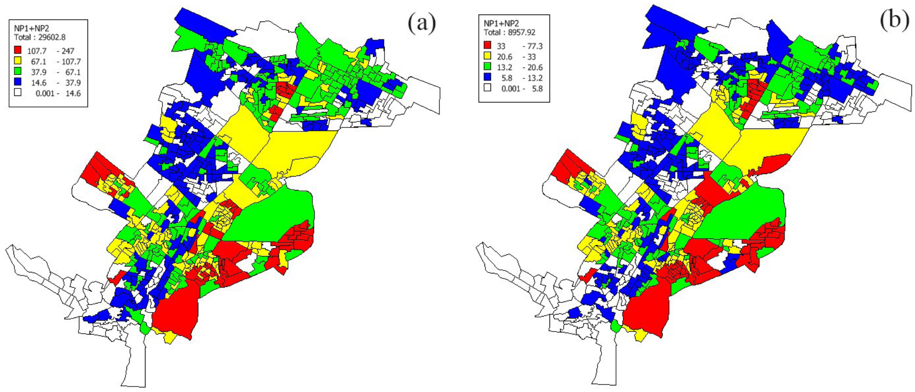

Figure 13. Number of people with P1+P2 level of injury, (a) MCE, (b) DBE

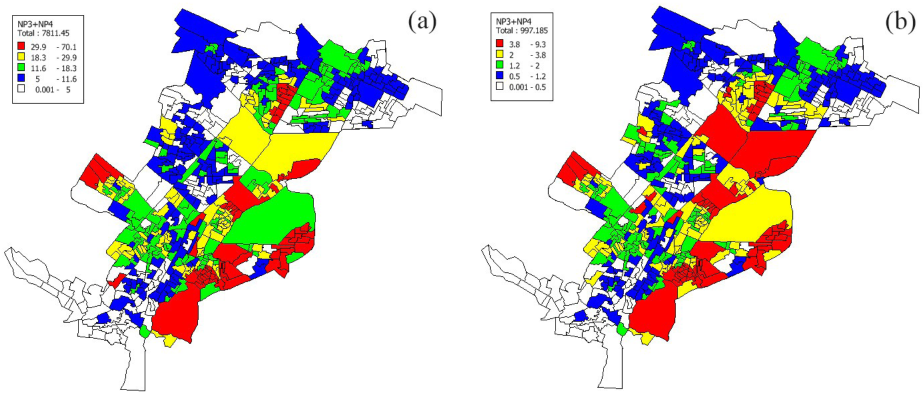

Figure 14. Number of people who lose their lives (P3+P4), (a) MCE, (b) DBE

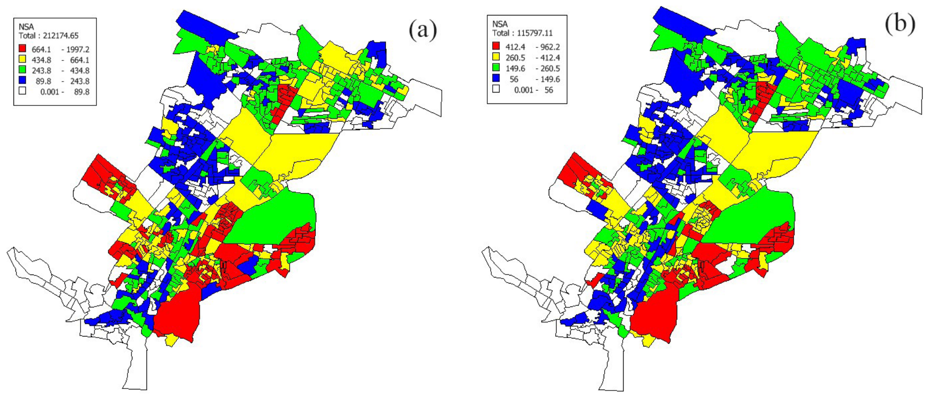

Figure 15. Number of homeless people (SA), (a) MCE, (b) DBE

8- Summary and conclusions

The seismic vulnerability of the masonry buildings of Kermanshah city that use no horizontal and vertical ties in their structure, is investigated by first level of RISK-UE method and implementation of the two earthquake scenarios in GIS based software of ARMAGEDOM. Due to change of population and its distribution in times, such GIS analysis is important to have new and up to date information available for the governments and plan seismic risk reduction and management programs.

The masonry buildings are mostly located in old and cultural texture of Kermanshah and are categorized as brick wall and wooden beam buildings (M1), brick wall and steel beam buildings (M2), and adobe buildings (A1). The seismic vulnerability of the three mentioned masonry buildings reveals that in DBE scenario that is an earthquake with return period of 475 years, about 12 percent of M1, 11 percent of M2, and 29 percent of A1, buildings experience sever damage of complete collapse. The same analysis for the MCE scenario that is an earthquake with return period of 2475 years, shows more than 42 percent of M1, 39 percent of M2, and 66 percent of A1, buildings experience sever damage or complete collapse.

The seismic vulnerability of buildings is used to evaluate the social impacts of the earthquake scenarios. The vulnerability of people to earthquakes reveals that out of 243195 persons living in the masonry buildings during the earthquakes, 8957 persons (3.7%) are injured and require health cares, 997 (0.4%) persons die, and 115797 persons (47.6%) are homeless and need shelters in a DBE scenario. The same analysis for MCE scenario shows, 29602 persons (12.2%) are injured and require health cares, 7811 (3.2%) persons die, and 212174 persons (87%) are homeless and need shelters. It is worth noting that these results are obtained only based on structural damage or collapse, and other side effects of an earthquake like mental or psychological impacts are not considered. These analyses present useful information of the current situation of Kermanshah and can be compared with the available potentials of social services to reduce the seismic risks.

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