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ARTICLE

AN EVALUATION OF SEISMIC VULNERABILITY OF BUILDINGS IN GANAVEH, IRAN

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ABSTRACT

Seismic vulnerability is a term used to indicate extent and amount of damages caused by natural disasters to communities, buildings and geographical zones. Evaluation of seismic vulnerability of existing buildings is actually a kind of damage potential prediction under probable earthquakes. The ideal method is to conduct a series of statistical analyses on sufficient sample sizes of similar subjects exposed to the same seismic performance. The present study aimed to evaluate seismic vulnerability of buildings in Ganaveh, so that by studying the current situation of buildings and determining their qualitative vulnerability, one can provide general guidelines to improve existing conditions. In this study, after referring to seismicity and geological characteristics of Ganaveh, recognizing different seismic vulnerability evaluation methods and selecting the appropriate qualitative evaluation procedure according to construction conditions of the case study area and field data collection method, seismic vulnerability of various types of buildings in Ganaveh were presented in bar charts independently using the modified Arya method. Based on the results obtained from the present study, most of masonry buildings, in particular in district 1, and some of steel or concrete structures have the risk of serious structural damages under moderate to major earthquakes. Therefore, immediate vulnerability assessment and retrofitting are highly required.

KEY WORDS
seismic vulnerability, qualitative evaluation method, seismicity

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INTRODUCTION

Evaluation of seismic vulnerability of existing buildings is actually a kind of damage potential prediction under probable earthquakes. The ideal method is to conduct a series of statistical analyses on sufficient sample sizes of similar subjects exposed to the same seismic performance [1]. Reviewing the available literature indicates that various methods have been used to evaluate seismic vulnerability of buildings and major arteries. Due to construction conditions in our country, poor quality of design and incorrect implementation of many existing and under construction structures, and according to conducted studies, one can see the fact that vulnerability assessment methods used in industrialized countries cannot be directly applied in our country. The earliest activities in this field date back to the early 1970s, when non-linear models were proposed to identify structural behaviors. Whitman (1972) was the first researcher who proposed a method for estimating seismic damage. In his method, the ground motions were modified in Mercalli scale and earthquake damage was expressed as the ratio of repairing cost to rebuilding cost (damage ratio). Bigassu and Bresler (1979) proposed an earthquake damage assessment method using the semi-static structural analysis. Two variables including final deformation capacity of elements and impact factors are taken into account for applying these methods to real buildings. The proposed methods in the previous studies have defined structural damage as the ratio of demand or response under the desired earthquakes to ultimate capacity of the structure. Kabanassu Penitu (1997) in a study referred to ground motions as the potential of damage and provided a better assessment of seismic risk by estimating parameters associated with damage expressed in terms of ground motion energy. Using neural networks is one of the most modern methods in vulnerability assessment which has been widely studied today [2]. In Iran, there are not enough studies on evaluation of seismic vulnerability of buildings. Shakib et al. have studied conventional vulnerability in the country. In this paper, we studied four types of buildings including steel, concrete, unreinforced masonry and complex buildings, which constitute a significant percentage of the country buildings. In this study, detailed buildings technical information forms were filled out for six different regions of the country using field data, and then performances of conventional buildings in recent earthquakes were evaluated to determine vulnerability of four types of conventional buildings. Studies conducted by Hassanzadeh and Nateq Elahi can also be cited in this field. They evaluated vulnerability of a 4-storey steel structure using nonlinear dynamic analyses. Razani and Bornaei proposed a practical model which has been used in Ahvaz. These researchers are completing a major theoretical and empirical model, under EVA, naming Iranian seismic vulnerability model. Tehranizadeh et al. investigated damage assessment procedures and retrofitting methods for masonry buildings against earthquakes and provided criteria and methods for seismic retrofitting. Nateq Elahi and Motamedi evaluated vulnerability of reinforced concrete buildings using nonlinear dynamic analysis. They designed a number of similar reinforced concrete buildings with the same plan and characteristics but different floors in two categories, with shear walls and without shear walls, based on the common structural codes in Iran. Then, they used IDARC program for nonlinear analysis. Seismic capacity of reinforced concrete buildings has been studied quantitatively by generalizing results obtained from the samples, and eventually their seismic vulnerability has been investigated by analysis of results. Barakchian (1999) presented a study entitled “A quantitative vulnerability assessment of important steel buildings against earthquakes using inelastic analyses”. Shakib et al. carried out studies entitled “Vulnerability evaluation of conventional urban buildings” to recognize construction conditions in different cities of Ilam province in terms of seismic resistance. Such studies are recommended for other cities of Iran due to the seismicity of most parts of the country.

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General Specifications of Ganaveh
Geographical Location

Ganaveh is a city located at 150 km from Boushehr with a population of about 120 thousand people. This city is located in the vicinity of some known faults such as Kazeroon fault, Misan fault etc. Because of locating in Zagros zone and having Folded Zagros tectonic properties, Ganaveh has a major share in the seismicity regional division. Locating in Alpine-Himalayan belt, movement of Saudi Arabia shield toward Iran, the lack of isostasy despite homogeneity in the crust structure, and partly tectonics related to formation of salt diapirs are the most important tectonic factors affecting seismicity of this zone. These factors, during the history, led to the exposure of this zone among the high risk zones which are classified as the middle class in terms of quality (with a relatively high risk domain and destruction) and in the 7th intensity class in terms of quantity.

Characteristics of Ganaveh Different Districts
To obtain perfect urban planning based on spatial structure of Ganaveh, the city is divided into seven districts within legal limits. Table 1 indicates population and area of each district. District 1: A region with an area of 240.5038 hectares and a population of 20,419 people located at the southwest of Ganaveh. This district is actually the oldest district of the city.

Table 1: Population estimation and area of case studies in Ganaveh

District	Estimated population in 2006	Area in hectares	Gross population density (persons per hectare)
1	20419	240.5038	85
2	16575	225.2990	73.6
3	9217	257.6772	35.8
4	2521	184.56	13.7
5	18164	258.1929	70.3
6	20997	219.7227	95.6
7		148.7788	
Total	878775	1534.7365	57.26

District 2: District 2 had an area of about 225.2990 hectares and a population of 16575 people in 2006. The gross population density was equal to 73.6 people per hectare. Total urban and rural per capita in this district was equal to 135.93 m2 and 89.2284 hectares of this district have been assigned to residential land use. Residential land use per capita in this district was equal to 53.83 m2.
District 3: This district is located at the southeast of Ganaveh with an area of 257.6772 hectares and a population of 9217 people. The gross population density is equal to 35.8 people per hectare. Total urban and rural per capita in this district is equal to 279.57 m2.
District 4: This district is located at the northeast of Ganaveh with an area of 184.5619 hectares and a population of 2521 people. The gross population density is equal to 13.7 people per hectare.
District 5: This district with an area of 258.1929 hectares has a population of about 18146 people. The gross population density is equal to 70.3 people per hectare and 92.2958 hectares of this district have been assigned to residential land use. Residential land use per capita in this district is equal to 50.86 m2.
District 6: This district with an area of 219.228 hectares has a population of about 20997 people. The gross population density is equal to 95.6 people per hectare.
District 7: This district is located at the northern part of the city with no inhabitants and an area of approximately 148.7788 hectares. About 51.0956 hectares of this area have been assigned to urban context lands and 6832 hectares have been assigned to non-functional lands.

Table 2: The most important earthquakes occurred in the vicinity of the case study in the twentieth century

The year of earthquake event	The depth of the epicenter (km)	Magnitude in richter
December 1925	149	5.5
May 1927	16	6.2
July 1927	33	6.2
February 1930	33	5.5
May 1930	-	5.8
July 1931	33	5.6
January 1950	6	5.5
February 1956	47	5.7
March 1956	36	5.8
April 1958	43	5.5
August, 1964	28	5.6
April 1972	33	6.9
April 1976	24	5.7
February 1985	37	5.3

Seismicity of the Region

Review of the history of past earthquakes records provides one of the fundamental data to assess the risk of earthquakes and seismicity. Table 2 presents characteristics of several earthquakes occurred in the region. Because of locating in Zagros zone and having Folded Zagros tectonic properties, Ganaveh has a major share in seismicity regional division. Data recorded in 85-year period (1985-1990) were used to study seismicity of the region.

MATERIALS AND METHODS

Vulnerability Evaluation Methods

During an earthquake, destruction or any structural damages begin from structural weaknesses. After failure of the first weak point, the other points are threatened by the earthquake forces. Therefore, detection of structural weaknesses, or in the other word, weakness detection standard is the first step, and then assessing appropriate repair and retrofitting methods, or in the other word, treatment standard is the second step in structural vulnerability studies against earthquake risks. Over the last twenty years increasing efforts have been conducted to assess seismic resistance of buildings. However, due to the diversity of buildings and the complexity of the effects of various parameters on seismic vulnerability of buildings, it is very difficult to develop standards for weakness detection and treatment. Based on the studies conducted around the world, structural vulnerability evaluation methods can be divided into two groups: quantitative and qualitative methods [3].

Arya Vulnerability Evaluation Method

This method which is proposed by professor Arya, shows the damage ratio of each structural parameter and finally the entire building total damage ratio based on different earthquake intensities. In this method, just like the other qualitative methods, the corresponding questionnaires are filled out first. Type of land, type of structural system and quality of construction are some of the main parameters in these questionnaires. A damage coefficient is assigned to each of the parameters for intensities of 7, 8, and 9 MSK. Then damage ratio which is a value between 0 and 1 is obtained using a mathematical relation between damage coefficients. By classifying damage ratios, one can estimate the building vulnerability. Arya vulnerability evaluation method, just like the other qualitative methods, has classified tables containing the main vulnerability parameters and indicators as well as damage coefficients; so that damage coefficients can be calculated for different earthquake intensities. In this method, damage coefficient between 0 and 4 has been determined for 7, 8, and 9 MSK intensities in terms of the indicator effect on structural damage. In the Arya method, amount of damage is determined as a value between 0 and 1 using building damage ratio which is the sum of damage coefficients effects via damage ratio equation. The damage to the building is determined based on the obtained damage ratio. The following four degrees of damage can be considered in estimating building damages [4]: - More than 75%: failure and loss, possibility of deaths; - 25% to 75%: high damage, forced evacuation of the building, reconstruction is required; -25% to 50%: moderate damage, requires repair after evacuation of the building; - Less than 25%: low damage, the building is usable, minor repairs without the need of evacuation. The following table shows how to calculate damage coefficients for buildings with given indicators and parameters. The main indicator parameters include: 1- land slope, 2- type of land, 3- type of structural system, 4- type of floors system, 5- the building height, 6- openings and walls, 7- cornices, 8- form of plan, 9- facade, 10- construction quality. Among the 10 mentioned parameters, parameters of 1, 2, 5, 6, 8, and 10 are not associated with structural elements and just affect structural behavior during earthquake events. These parameters are graded so that if an earthquake with an intensity of 7, 8, 9 MSK occurs in the region, the effect of each parameter on the structural behavior can be determined. Damage coefficient of Li is used to obtain the 4 remaining parameters which are associated with structural elements, and if they are damaged, they will be loss, or damage the other elements. For instance, walls or columns collapse leads to collapse of roof or the entire building and reconstruction will be needed. These parameters are calculated using F coefficients which reflects cost of each parameter to the cost of the entire building. These four parameters and the related F coefficients are as follows: type of structural system: F4=0.6; floor system: F5=0.33; cornices (turrets, balconies): F7=0.04; façade materials: F= 0.03. F coefficients are selected approximately and user can change them based on building cost estimation. However, the sum of these factors should not be greater than 1 (representing the total cost of the building). Damages to each parameter in the second class vary in the range of 0 to 4. When this range is divided by 4, the results will vary between 0 and 1. Here, 0 reflects no vulnerability or lack of damage and 1 means collapse or damage of the entire building. The total damage of the building can be calculated as follows: After determining the parameters of Fi and Li, damage ratio of the entire building can be calculated from equation (1).

$$LR = l_1 \times L_2 \times L_5 \times L_6 \times L_8 \times L_{10} \times \frac{1}{4}[(F_3 \times L_3) + (F_4 \times L_4) + (F_7 \times L_7) + (F_9 \times L_9)] \leq 1$$

LR values should vary between (0 to 1) so if a value more than 1 is obtained from calculation, we should consider it as 1. Finally, vulnerability of the building against earthquakes based on LR damage ratio values obtained from the above equation are evaluated as Table 3 and 4. Due to compatibility of the Arya method with the local construction requirements, it can be completed with expert studies. To achieve accurate results, paragraphs of evaluation table are modified as follows:

A- LA1 paragraph is added to the table for foundations which are not considered in Arya method. In this paragraph,

suitability of footing beam in intensities of 7, 8, 9 MSK is considered as affectless and the effect of its inappropriateness is also considered as a ratio of 1.05 just in intensity of 9 MSK. Non-implementation of foundation or footing beams which have a significant impact on the lack of structural resistance are considered as 1.05, 1.10, and 1.15 for the intensities of 7, 8 and 9 MSK, respectively. The lack of foundation resistance will cause structural weaknesses and serious damages to the building. Therefore, this parameter is considered as the main parameter in the LR coefficient group.

$$LR_r = L_1 \times L_2 \times L_3 \times L_5 \times L_8 \times L_{A1} \times L_{A2} \times L_{10_1} \times \frac{1}{4}(F_7 \times L_7) + (F_9 \times L_9)\Big] \leq 1 \tag{2}$$

Table3: Structural vulnerability based on damage ratio in the quick qualitative method

Diagnosis (damage level)	Variation range LR
Probablity of collapse	LR>0.75
High vulnerability	0.50<LR<0.75
Moderate vulnerability	0.25<LR<0.50
Low vulnerability	LR<0.25

RESULTS

Results of Seismic Vulnerability Evaluation in the Case Study

Based on municipal divisions, Ganaveh is divided into seven districts. Sampling in each of these districts was performed based on the percentage of existing buildings types (in terms of structural system, number of floors, etc.). To evaluate building performance, we need some criteria to assess building safety. Before analyzing obtained technical data, buildings were divided into seven categories based on their structural systems including: steel structural buildings with braces, steel structural buildings without braces, masonry buildings without footing beams. To assess and compare, different distribution systems of Genaveh residential buildings are presented in table 6 in terms of the type of structure and building materials. Field data, after being analyzed, were presented as bar charts for districts 1 and 2, which are the higher dense districts. These charts are plotted based on damage index in earthquakes with intensities of 7, 8 and 9 MSK. The vertical axis in these charts indicates damage index varying between 0 and 1. For engineering judgment about vulnerability of each building, the vertical axis is divided into intervals of 0.25 according to Arya method criteria. Criteria related to the seismic vulnerability are presented in the paragraph. Most masonry buildings are very vulnerable under the influence of major earthquakes. Most masonry buildings without rewinding will collapse in a moderate earthquake. In some masonry buildings, with only horizontal footing beams, collapse is probable even during a moderate earthquake. Most masonry buildings with horizontal and vertical rewinding and proper implementation, collapse is probable even during a moderate earthquake.

Table 4: The modified Arya table [5]

Damage index	Parameter and its coefficients	Sub-parameters	Damage coefficient (L) Intensity of 7	Intensity of 8	Intensity of 9
(L1)	Land slope (degree)	0-15	1	1	1
		16-30	1	1	1.1
		>30	1	1.1	1.2
(L2)	Type of land	Hard (I)	1	1	1
		Medium (II)	1	1.1	1.2
		Soft (III)	1.1	1.2	1.3
		Fluent (IV)	1.3	1.5	2
LA1	Foundations and footing beams	Appropriate foundations and footing beams	1	1	1
		Inappropriate foundations and footing beams	1	1	1.05
		Non-implementation of foundations and footing beams	1.05	1.10	1.15
(L3)	Type of structural system F3=0.6 If the facade cover does not exist L9 must be removed F3=0.63	Steel structure with braces	0	0.5	1
		Steel structure without braces	1	1.2	2
		Reinforced concrete structure	1	1.2	2
		Masonry wall without brick rewinding	1.2	2.5	3.5
		Masonry wall with horizontal brick rewinding	1	1.5	2.5
		Masonry wall with horizontal and vertical brick rewinding with appropriate implementation	1.5	2	3
		masonry wall with horizontal and vertical brick rewinding with poor implementation (in terms of integrity and rewinding	0	1.5	2.5
		Masonry wall with horizontal and vertical rewinding with concrete blocks and proper implementation	1	2	3
		Masonry wall with horizontal rewinding and concrete block	1	1.7	2.7
		Masonry wall with horizontal and vertical rewinding and poor cement blocks (in terms of integrity and rewinding)	1.5	2.5	3.5
		Masonry wall with cement block without rewinding	1.5	2.5	3.5
		Complex	2.5	3.5	3.5
(L4)	Floor system F4 = 0.33 (if the cornices are appropriate or do not exist, L7 is removed F4=0.37)	Arch percussionist with appropriate support	1	1.5	3
		Arch percussionist with inappropriate support and arch foot	2	3	4
		Block joist with appropriate general, support and rebar cover conditions	1	2	3
		Block joist with inappropriate general, support and rebar cover conditions	1.5	2.5	3.5
		Reinforced concrete slab	0	0	1
		Wooden roof with light coating	0	1	1.5
		Wooden roof with building materials	2	3	4

		Light metal ceiling with horizontal bracing	0	1	1.5
(L5)	Building height	One-storey masonry building with steel and concrete structure up to three floors	1	1	1
		Two-storey masonry building with steel and concrete structure higher than three storeys	1.1	1.2	1.3
(L6)	Wall opening with building materials	Satisfying	1	1	1
		Exceeding	1.1	1.2	1.3
(L7)	Cornices F7=0.04	Satisfying	0	0	0
		Exceeding	1	1	11
(L8)	Irregularity in plan with altitude	Regular	1	1	1
		Irregular	1.1	1.1	1.1
(L9)	Façade F9=0.03	(Brick / stone) stationary	0	0	0
		(Brick / stone) non-stationary	1	1	1
		Concrete facade	0	0	0
		Mud	0.5	0.5	0.5
(L10)	Building quality (according to age of the building and implementation conditions)	Good	0.6	0.6	0.6
		Medium	0.8	0.8	0.8
		Bad	1	1	1
LA2	Construction development and discontinuity seam considerations in buildings of over 4 floors.	Interaction between behavior of the new building and the behavior of the original building High (in this case the building is evaluated as weak)	-	-	-
		Medium	1.1	1.3	1.5
		Low	1	1.1	1.2
		No development	1	1	1

Table 5: Distribution of Ganaveh housing units based on type of structures and the main materials

Type of structure and materials	Number	Percentage
Steel structure	171	1.32
Reinforced concrete	1269	9.8
Brick and iron or stone and wood	7127	55
Brick and wood or stone and wood	2321	17.9
Cement block	1563	12.07
Brick or stone	220	1.7
Wooden	28	0.22
Brick and wood	37	0.28
Brick and mud	4	0.03
Other types	37	0.29
Undeclared materials	24	0.19
Undeclared type of structure	152	1.2

Semi-steel buildings may collapse in moderate earthquakes with intensity of 8 MSK and receive high damages in earthquakes with an intensity of 7 MSK and totally have the worst vulnerability conditions. The most masonry buildings receive moderate damage during moderate earthquakes with the intensity of 8 MSK, but the most important masonry buildings without rewinding will receive high damages in such earthquakes. The results of steel structures differ due to the structural system, so that steel buildings with braces have the minimum damage ratio and the steel buildings without braces will have the maximum vulnerability. Buildings without braces are probably destroyed in earthquakes with intensity of 9 MSK. Buildings without braces belong to moderate damage group in moderate earthquakes, but important buildings are considered in the high damage group. Buildings with braces, even in the worst conditions i.e. the major earthquakes, belong to the moderate damage group and are slightly damaged in medium earthquakes. Concrete buildings, which totally have a relatively better status, will receive moderate damage in the event of a major earthquake and very low damage in moderate earthquakes. Concrete buildings located in district 2 will receive moderate damage in the event of a major earthquake and very low damage in moderate earthquakes. Important buildings with reinforced concrete structure are placed in high damage group in high-intensity earthquakes and in moderate damage group in moderate earthquakes. So, we need to estimate vulnerability of these buildings and retrofit them immediately. The Immediate action can be taken with the aid of improvement guidelines [6, 7].

CONFLICT OF INTEREST
There is no conflict of interest

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