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Evaluation of Seismic Vulnerability of Concrete Buildings Based on Different Indices of Damage (Case Study: Office Buildings in Bandar Abbas)

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Abstract: Evaluating the vulnerability of existing buildings is in fact a prediction of damage against possible earthquakes. In this regard, the existing building structures vulnerability prediction of possible future earthquakes is one of the most pressing engineering measures due to provide solutions for seismic risk reduction in urban areas. Various constructions with concrete structure in Bandar Abbas which lack the appropriate lateral force resisting systems added to the low quality of implementation, inappropriate quality of building materials and environmental conditions have caused the vulnerability of buildings against earthquakes. Consequently, recognizing structural weaknesses and evaluating them against earthquakes is of great importance for the building's improvement. This study aims to achieve the recognition of the existing state office buildings in Bandar Abbas from the perspective of seismic resistance and seeks to assess the quantitative and qualitative vulnerability of two office buildings using different indices of damages and tries to answer the question whether the implemented concrete structure of the office buildings in Bandar Abbas have a good performance against earthquake or not. Accordingly, technical specifications and implementation plans for the two office buildings were collected including administrative plans, executive details and laboratory sheets and then the vulnerability of buildings were assessed by the modeling in Etabs and Sap 2000 Software using non-linear analysis (static and dynamic) and using qualitative evaluation methods of Aria, Canada by laws and ATC-21 as well as a quantitative assessment methods of Raphael-Mir, Suzan, Newmark and Rosen Blow. The results showed that from the 848 proposed joints in the public library building in Bandar Abbas, 24 joints are on the verge of Collapse (CP) and 14 joints are in the range of Life Safety (LS). In civil status registration organization building in Bandar Abbas, there are 236 proposed joint in the total structure of the building among which 11 jointsare on the verge of Collapse (CP) and 3 jointsare in the range of Life Safety (LS). The results of the vulnerability of buildings using Raphael-Mir, Suzan, Newmark and Rosen Blow index show that the public library building in Bandar Abbas in these methods (the design-based earthquake in the general bylaws of buildings against earthquake) will be totally damaged and civil status registration organization building will also be totally and generally damaged in these methods in the life safety and general vulnerability.

Key words: Seismic vulnerability, damage index, Bandar Abbas, concrete buildings, perspective

INTRODUCTION

The lack of engineering design and construction of buildings based on regulations, poor quality of materials used, weather conditions and shortage of skilled laborer and the lack of lateral systems have rendered most existing concrete buildings as half-resistant and non-resistant buildings in an earthquake. Therefore, in moderate or strong earthquakes they can cause considerable damage. Building structures vulnerability prediction caused by possible future earthquakes is one of the most pressing engineering measures in order to provide appropriate solutions to reduce seismic risk in urban areas. Recognizing the weak spots of buildings as the first step and improvement as the second step are posed in the study of seismic vulnerability of structures against earthquake risks since at the time of the earthquake, building damage or collapse will start from the weak points. To provide an indicator to determine the vulnerability of structures against earthquakes is something that has attracted the attention of researchers for more than three decades. For this purpose, knowing the damage index of a structure we can have an appropriate understanding of its behavior while earthquake as well as to specify the red lines of the action. On the other hand, the knowledge of how a structure is damaged is necessary for rehabilitation programs in order to control the status quo. In other words, finding the malfunction indicator in a structure specifies how the structures arestable against lateral forces such as earthquakes. Activities in the history to determine the malfunction indicator refer back to the early seventies and the history of activities in the field of study of the vulnerability of buildings refers back to early seventies. At the same time, non-linear models were proposed to assess the behavior of structures against earthquakes. In 2011, Gholamin and Falahati assessed the seismic vulnerability of 200 buildings with different structural systems in the city of Tabriz using Aria Method. The results showed that the majority of masonry buildings are in the first row of vulnerability due to earthquake (probability of collapse), metal buildings with bracings and reinforced concrete buildings are in the middle row of damage. In a survey entitled as evaluating the seismic vulnerability of reinforced concrete duplex structures against earthquakes, Qodrati *et al*. (2008) surveyed the floor damage index and total damage index in three 4, 8 and 10-storey buildings like the two Tabas and Alsenter earthquakes and 0.3 g, 0.5 g and 0.7 gPGAs using non-linear dynamic analysis software: IDARC. The results showed that all upper floors of both structures in the 0.3 g have the most damage (Qodrati *et al*., 2008). Belheouane and Bensaibi (2013) assessed the seismic vulnerability of reinforced concrete buildings in Algeria. They assessed the vulnerability of reinforced concrete buildings in Algeria using a vulnerability index based on structural and non-structural parameters of buildings which includes the summation of numeral indices' points of seismic quality of buildings and also by preparingthe earthquake probability matrix degradation. Aftabur and Shajib (2012) aimed at evaluating the different methods of assessing vulnerability to criticize them including: history, basic concepts, qualitative methods and advances in technology and development of their seismic vulnerability assessment methods. The results showed the vulnerability of seismic methods have developed with the development of advanced technologies and choosing one of these methods depends on the purpose and accuracy of the study. The results also showed that vulnerability methods based on statistical method and desert monitoring techniques are far better than other methods in the analysis of the vulnerability of large-scale. Valente (2013) assessed the seismic protection of concrete reinforcement brace payment system with the aim of improving the seismic performance of reinforced concrete frames using a method based on energy X-shaped bracing panel to review the ductile shear. The results of non-linear analysis of reinforced four-storey concrete frame designed based on weight showed that reinforcement bracing system could be vulnerable to serious earthquakes, to protect the basic structure of the frame structure.

Sadat assessed the seismic vulnerability of buildings in the city of Dhaka using a combination of fast visual assessment and measurement of Turkey and earthquakes indices such as the type of building, size and shape of the buildings, empty spaces within the structure and foundation, slab type, year of construction, number of floors and finally, analysis of measured parameters. The results showed that many buildings are built without taking proper system to prevent earthquake damage. Nasiriamiri and Naghipour assessed the qualitative evaluation of a number of schools in Tehran made during 1989-1999 by using aria techniques and saba (Venezuela) and modified combined method. The result showed that a qualitative combination assessment method as well as an overall assessment method is appropriate methods for buildings with less importance and for buildings with great importance accurate analytical methods must be used. Zahraei and Ershad assessed the status of existing buildings in the city of Qazvin, using aria modified method. They found that most of the masonry buildings, especially in the 1st zone of Qazvin City and some buildings with steel or concrete skeleton are at risk of serious instrumental damage against moderate to severe earthquakes (Madi and Leily, 2005). Other studies include Lang and Bachmann (2004) and Otani (2000). Bandar Abbas is situated in the zone of relative risk of an earthquake with a high probability of experiencing an intense earthquake that can cause the damage to the structures and buildings. There should be the right decision taken for assessing the damage in order for strengthening or the continuation of service and restructuring them due to the importance of preventing loss of life and property damage to buildings. This study reviews the current status of buildings in Bandar Abbas, especially buildings with office functions from the point of view of seismic resistance and tries to show whether the structures of concrete buildings in Bandar Abbas has a good performance against earthquake or not using non-linear analysis and different indicators.

MATERIALS AND METHODS

This study examines the vulnerability of two office buildings in Bandar Abbas including the public library and the registry office buildings. Figure 1 and 2 show the plans of studied buildings. Registry office buildingis a building with reinforced concrete structure with an area of 317 square meters per floor in which walls are formed with 3D panels and the ceiling is formed with concrete slab. The building is built in the land of type III on the basis of regulations against earthquake (the standard of 2800) and is placed among the moderate important buildings. The plan of building is irregular and the skeleton system of the building is flexural by the two sides and in 2 floors. The

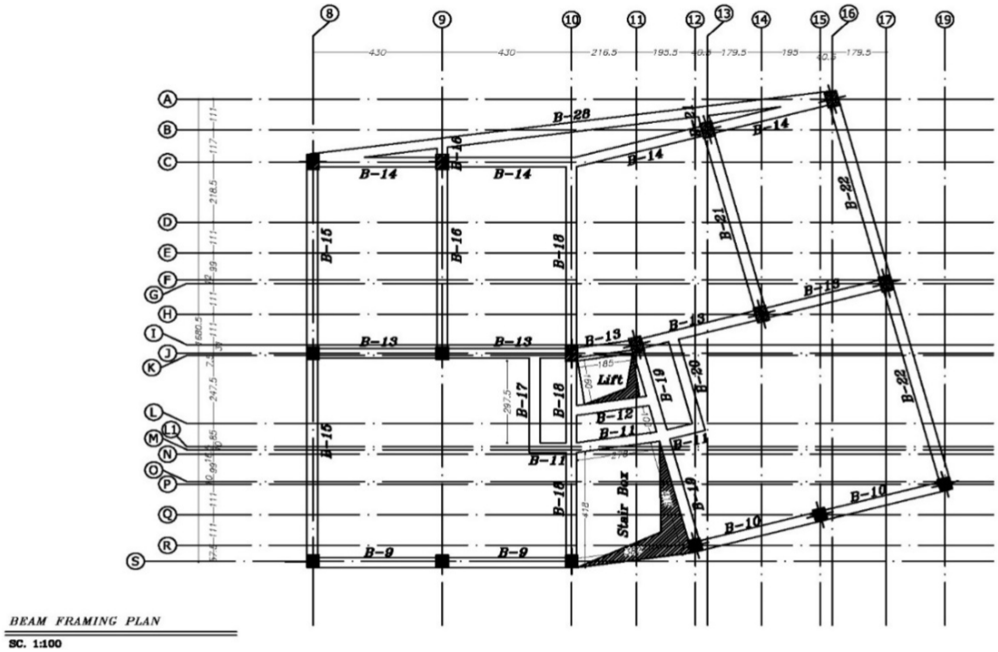

Fig. 1: The plan of registry office building in Bandar Abbas

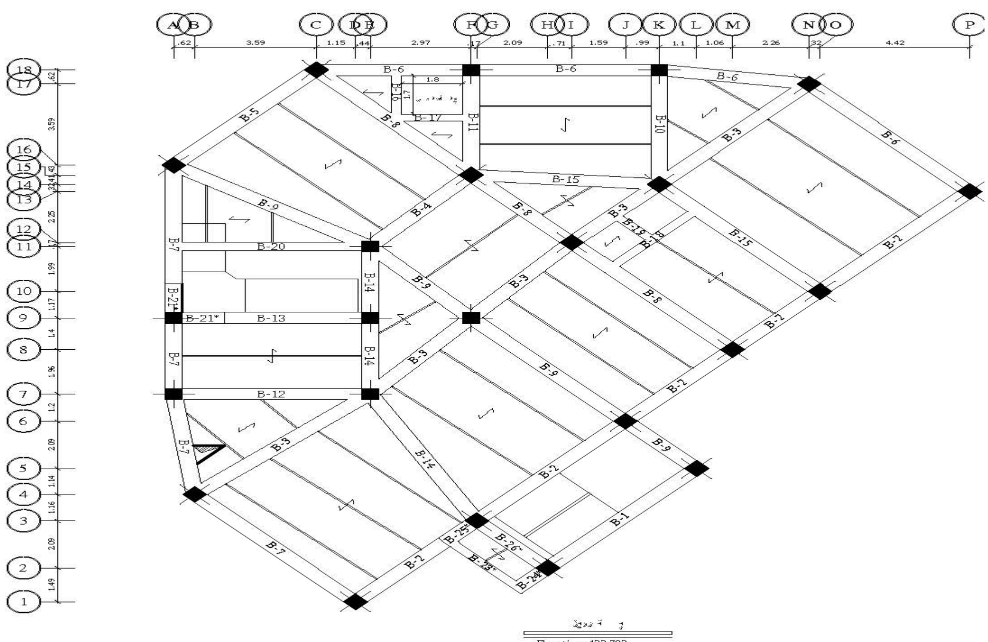

Fig. 2: The plan of public library building in Bandar Abbas

building of public library is a building with reinforced concrete structure with an area of 411 square meters per floor the walls of which are of tile and the ceiling is made up of composite material. The building is built in the land of type III on the basis of regulations against earthquake (the standard of 2800) and is placed among the high important buildings. The plan of building is irregular and the skeleton system of the building is flexural by the two sides and in 3 floors.

Methodology: This research method is based on quantitative and qualitative data and information

OCCUPANCY			SOIL		TYPE						FALLING HAZARDS			
Assembly	Govt	Office	Number of Persons		A	B	C	D	E	F	☐	☐	☐	☐
Commercial	Historic	Residential	0 – 10	11 – 100	Hard Rock	Avg. Rock	Dense Soil	Stiff Soil	Soft Soil	Poor Soil	Unreinforced Chimneys	Parapets	Cladding	Other: ______
Emer. Services	Industrial	School	101-1000	1000+										

BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	**4.4**	**3.8**	**2.8**	**3.0**	**3.2**	**2.8**	**2.0**	**2.5**	**2.8**	**1.6**	**2.6**	**2.4**	**2.8**	**2.8**	**1.8**
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.4	+0.4	+0.4	+0.4	+0.2	N/A	+0.2	+0.4	+0.4	0.0
High Rise (> 7 stories)	N/A	N/A	+0.6	+0.8	N/A	+0.8	+0.8	+0.6	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	N/A	-1.0	-1.0	-1.0	-1.0
Plan irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-0.2
Post-Benchmark	+2.4	+2.4	+1.4	+1.4	N/A	+1.6	N/A	+1.4	+2.4	N/A	+2.4	N/A	+2.8	+2.6	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6	-0.6
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8
FINAL SCORE, *S*															

COMMENTS	Detailed Evaluation Required YES NO

Fig. 3: Sample required data collection forms by ATC-21 (Fema-154)

gathering, site visits, preparing a questionnaire and then analyzing the collected data. In this context, information of administrative maps and soil mechanics' test results of the study were collected for the two buildings and damage index was estimated using qualitative and quantitative vulnerability and also modeling Software of Etabs and excell. The steps are summarized as follows:

Qualitative assessment method for buildings: Special forms are prepared in qualitative methods according to the seismic terms and construction conditions and based on the experience of past earthquakes. Using these forms, building inspectors store information such as vertical load-bearing system, lateral seismic resistant system, quality fittings, flexibility of members, method of construction, condition of the building and the foundation in a database. These methods can be used to estimate the approximate capacity of primary and seismic resistance of buildings used in a particular area. Of the qualitative methods we can mention the saba proposed vulnerability assessments method developed by applied technology association of america, aria vulnerability assessment (Arya, 1967), regulations of New Zealand, the Code of Japan and the vulnerability assessment of canada. In this study, ATC-21 and regulations of Canada were surveyed for the studied buildings based on the vulnerability of Aria.

ATC-21 Method: The rapid assessment ATC-21 basis is the classification of building based on the type of lateral force system and determining a Basic Structural Hazard (BSH) for it. Lateral force system is determined based on the information that is already available such as counselor's database, the date of manufacture as well as eyewitness. Then, the basic structural damage is determined and is reform by adding or subtracting the Performance Modification Factors (PMFs) in order to achieve the final structural degree, S. The basic damage degree, performance modification factors and the final degree of structure are related to the probability of the total structural collapse of the building. Forms to collect information about the building and how to obtain the structure must be done by a qualified professional person or an engineer. A safety number will be assigned for each of the items listed. In this way, different weaknesses are cited as negative numbers and the final safety number is achieved by reducing negative numbers of weaknesses from the total number of safety. The $2<S<3$ limit is considered as a suitable range for S and a value close to 2 is considered to be an appropriate amount if a certain amount for seismic safety area is not specified. Figure 3 shows an example of data collection forms of buildings and the appropriateway to calculate vulnerability in this method.

The Aria Method: Qualitative vulnerability assessment method of Aria is common in Iran due to the simplicity and ease of application in order to estimate the vulnerability of the buildings of a vast neighborhood of a city and also the lack of need to exact architectural

Table 1: Calculation of the vulnerability of buildings by Aria approach

Index	Parameters	Sub-parameters	Loss ratio (L) The intensity of 7	The intensity of 8	The intensity of 9
L_1	The slope of land (degree)	0-15	1.00	1.00	1.00
		16-30	1.00	1.00	1.10
		>30	1.00	1.10	1.20
L_2	The kind of the land	Severe (I)	1.00	1.00	1.00
		Moderate(II)	1.00	1.10	1.20
		Soft (III)	1.10	1.20	1.30
		Smooth (IV)	1.30	1.50	2.00
L_{A1}	Foundations and ties	Appropriate foundations and ties	1.00	1.00	1.00
		Inappropriate foundations and ties	1.00	1.00	1.05
		The lack of foundations and ties application	1.05	1.10	1.15
L_3	The kind of structural system $F_3 = 0.6$ (if the laminate is not facade, the L_9 index should be deleted and $F_3 = 0.63$)	Metal skeleton with brace	0.00	0.50	1.00
		Metal skeleton without brace	1.00	1.20	2.00
		Reinforced concrete skeleton	1.00	1.20	2.00
		Masonry wall without brick skein	1.50	3.00	4.00
		Masonry wall with horizontal brick skein	1.20	2.50	3.50
		Masonry wall with horizontal and vertical brick skein for the appropriate implementation	1.00	1.50	2.50
		Masonry wall with horizontal and vertical brick skein for the weak implementation	1.50	2.00	3.00
		Masonry wall with horizontal and vertical concrete block for the appropriate implementation	0.00	1.50	2.50
L_3	The kind of structural system $F_3 = 0.6$ (if the laminate is not facade, the L_9 index should be deleted and $F_3 = 0.63$)	Masonry wall with horizontal skein with concrete block	1.00	2.00	3.00
		Masonry wall with horizontal and vertical skein with weak concrete block	1.00	1.70	1.70
		Masonry wall without skein with concrete block	1.50	2.50	3.50
		Half skeleton	2.50	3.50	4.00
L_4	Storey's floor system $F_4 = 0.33$ (if the jut is appropriate or does not exist, L_7 should be deleted $F_4 = 0.37$)	The barrel vault with appropriate base	1.00	1.50	3.00
		The barrel vault with inappropriate base and vault	2.00	3.00	4.00
		Block joint with appropriate general, base and fittings cover condition	1.00	2.00	3.00
		Block joint with inappropriate general, base and fittings cover condition	1.50	2.50	3.50
		Reinforced concrete slab	0.00	0.00	1.00
		Wooden ceiling with light cover	0.00	1.00	1.50
		Wooden ceiling with masonry material	2.00	3.00	4.00
		Light metal ceiling with horizontal bracing	0.00	1.00	1.50
L_5	The height of the building	A one-storey masonry building or a three-storey building with metal or concrete skeleton	1.00	1.00	1.00
		A two-storey masonry building or more than three-storey building with metal or concrete skeleton	1.10	1.20	1.30
L_6	Opening in the wall with masonry materials	Satisfactory	1.00	1.00	1.00
		Violating	1.10	1.20	1.30
L_7	Juts $F_7 = 0.04$	Satisfactory	0.00	0.00	0.00
		Violating	1.00	1.00	1.00
L_8	Disorder in the plan with height	Ordered	1.00	1.00	1.00
		Disordered	1.10	1.10	1.10
L_9	Facade $F_9 = 0.03$	(masonry/brick) fixed	0.00	0.00	0.00
		(masonry/brick) not fixed	1.00	1.00	1.00
		Concrete façade	0.00	0.00	0.00
		Soil	0.50	0.50	0.50
L_{10}	The quality of the building (due to the years of construction and implementation conditions)	good	0.60	0.60	0.60
		Moderate	0.80	0.80	0.80
		Bad	1.00	1.00	1.00
L_{A2}	The improvement of the building and seam interruption consideration in buildings more than four floors	The mutual impact of the new building in	-		
		the in the treatment of the main building	-	-	
		Very much (the building is evaluated as weak)	1.10	1.30	1.50
		Moderate	1.00	1.10	1.20
		Little	1.00	1.00	1.00
		No improvement	-	-	-

maps, structural calculations, implementing details, the exact characteristics of used materials and relevant consistency with the climate of the country. Other features include the ability to change and adapt to new systems using different instruments with conventional buildings. Aria vulnerability assessment methodology is classified in accordance with Table 1 including the main parameters and indices of vulnerability and loss coefficient so that they could be calculated for the different intensities of earthquake. In this method, the loss ratios are determined between 0-4 based on the effect of the index in the value of damage to the building for three seismic intensities of 7, 8 and 9 on the MSK (MSK1964 was presented by Medodov, Sponor and Carnik and the application was allowed using some experimental modifications in accordance with the International Intensity Scale specified by UNESCO international committee about the Seismology and earthquake engineering in April 1964) scale (Eq. 2).

In Aria Method, the amount of damage with the proportion of building's damage which obtained through the summation of the damage coefficients using damage proportion equation is determined by number and the damage to the building is calculated between 0-1 based on the amount of damage proportion obtained from Eq. 1. The evaluation is done in the estimation of the damage to the building on the basis of specified limits in Table 2.

Calculating the loss ratio:

$$\begin{aligned} LR = & L\_1 \times L\_2 \times L\_5 \times L\_6 \times L\_8 \times L\_A2 \times \\ & L\_A2 \times L\_10 \times 1/4[(F\_3 \times L\_3) + \\ & (F\_4 \times L\_4) + (F\_7 \times L\_7) + \\ & (F\_9 \times L\_9) \leq 1 \end{aligned} \tag{1}$$

Table 2: Judging the seismic vulnerability in Aria approach

Judgment	The area of damage
The probability of collapsing the building	$LR \geq 0.75$
High damage-the necessity of rebuilding	$0.5 \leq LR < 0.75$
Moderate damage-needs great deal of repairing	$0.25 \leq LR < 0.5$
Low damage-needs a slight amount of repairing	$LR < 0.25$

Regulations of Canada: Canadians have also prepared a bunch of information forms according to the ATC-21 and earthquake regulations of Canada which contains a Structural Index (SI) and a Non-Structural Index (NSI). Structural index is calculated according to Eq. 2 and Non-Structural Index (NSI) on the basis of Eq. 3:

$$SI = A.B.C.D.E \tag{2}$$

$$NSI = B.E.F \tag{3}$$

Where:

A = Seismicity of the place
B = Soil conditions
C = Type of building
D = Disorder
E = Importance
F = Non-structural hazards

Seismic priority index is achieved by adding the two indices. The score for each of the indices is used as a criterion for more complete assessment of buildings' rating in terms of priority. The higher the scores are the higher is the priority of intended structure for more study. Preliminary results of the evaluation test at 30-50 rank, shows the building more prone in the earthquake. Table 3 shows the evaluation criteria in Canada Method.

Quantitative assessment method for buildings: Seismic vulnerability assessment method is done shortly after the mapping and computer modeling and is examined with non-linear static and dynamic analyses of the studied building. The important aspects of this method Areto find

Table 3: Qualitative form of vulnerability assessment of buildings in Canada approach

Seismic control form — The raw numbers — Page

Seismic priority index-circle the appropriate amount

Parameters	The year of design	The efficient seismic area (if $z_\alpha > z_v$, Z_v or $Z_v = 1$ is chosen) 2	3	4	5	6	
A							= A
The seism amount	Before 1991, 1991-2000, after 2001	1.0	1.5	2.0	3.0	4.0	
		1.0	1.0	1.3	1.5	2.0	
		1.0	1.0	1.0	1.0	1.0	

	The year of design	The soil's condition rock or hard soil	Hard soil with >50 m depth	Soft soil with >15 m depth	Smooth or soft soil	Undefined soil	
B							=B
The soil's condition	Before 1991, after 1991	1.0	1.3	1.5	2.0	1.5	

The kind of structure and its sign

	Year (design)	Wooden WLP	Wooden WPB	Steel SLF	Steel SMF	Steel SBF	Steel SCW	Concrete CMF	Concrete CSW	Premade concrete PCF	Premade concrete PCW	Brick filler SIW. CIW	Brick PML. PMC	Brick URM	
C															= C
The BM of	Before 1991	1.2	2.0	1.0	1.2	1.5	2.0	2.5	2.0	2.5	2.0	3.0	2.0	3.5	
the source	BM, after	1.2	2.0	1.0	1.2	1.5	1.5	1.5	1.5	1.8	1.5	2.0	1.5	3.5	
year	1991 BM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

Table 3: Continue

Parameters	The year of design	Vertical	Horizontal	Short columns	Soft level	Hit	Betterment	Gradual corruption	None	D: the multiplication of circular numbers not more than 4
D										
The inconsistency of the structure	Before 1991,	1.3	1.5	1.5	2.0	1.3	1.3	1.3	1.0	-
	after 1991	1.3	1.5	1.0	1.5	1.3	1.0	1.3	1.0	-

	The year of design	The condition of soil: Low density (N.10)	Moderate density (N = 10-300)	School with high density (N = 300-301)	Vital and high density (N.3000)	Especial application	
E							= E
The importance of the structure	Before 1991,	0.7	1.0	1.5	2.0	3.0	
	after 1991	0.7	1.0	1.5	1.5	2.0	

Employed area x Employ density x Time factor = N; Time factor is equal to the employment of people per hour in the week divided by 100, not more than 1

The average of people employment per hour in the week	The density of employment based on employment divided by 100	Usage
1	5-50	Private
0.2	50-80	Public service
0.1	50-60	Productive or official
0.06	100	Domestic
0.01-0.02	100	Storage

SI = Structural index: SI = A.B.C.D.E

Non structural hazards	Description	The year of design	None	Yes	Yes	
F						F = max(F1, F2)
F1: Casualties		Before 1991, after 1991	1.0	3.0	6.0	
			1.0	2.0	3.0	
F2: Vital damages		Annual	1.0	3.0	6.0	

Only if more than one case of these descriptors are circled (SMF, CMF, soft level and twisting); NSI = Non structural index: NSI = B.E.F; SPI = Primary Seismic Index: SPI = SI+NSI

out the accuracy of the computer model and the dynamic parameters of the building. The consistency between the reality and computer models is essential for the important and vital buildings which must have non-stop service after the earthquake. In this respect, the accuracy of the computer model had to be investigated doing certain tests (10). Regarding the analytical seismic evaluation of the existing buildings, methods and different indicators have been proposed including indicators by Wang *et al.* (2007) and pushover method. In this study, quantitative vulnerability assessment of buildings is done using pushover, Raphael and Mir index, Suzan index and Newmark and Rosen Blow index.

Non-linear static analysis (pushover): In this method, the structure is moved laterally to a certain degree for functional level by nonlinear load combinations in order for the structure to be placed in the range of movements beyond life safety. The value of this shift in fema and instructions of seismic retrofitting of structures is called the target displacement the calculation of which is done using the following links. It should be mentioned that a non-inear static analysis is performed in Etabs first and curve cutting base is drawn against the lateral

Table 4: Approximate values of C_0 factor

All the buildings	--Shear buildings--		The number of floors
10	1.00	1.0	1
1.2	1.15	1.2	2
1.3	1.20	1.2	3
1.4	1.20	1.3	5
1.5	1.20	1.3	10 and more

displacement and sketched curves can be calculate thetarget shift (11). Target displacement calculation methods are as follows:

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g \quad (4)$$

Where:

- T_e = The building's main effective frequency time per seconds
- T_i = The main frequency time of the building, assuming the linear behavior from elastic dynamic analysis
- K_i = Elastic lateral stiffness of building
- K_e = Effective lateral stiffness of building
- C_0 = Correction factor for the spectral communication Shift range of system of one degree of freedom to roofing shift system of several degrees of freedom which are obtained based on shear and non-shear type of buildings and number of floors as follows in Table 4

C_1 = Correction factor for the inelastic shift of the system which is obtained from the below equation:

$$0.2<T_e<1 \Rightarrow C_1 = 1+\frac{R_u\text{-}1}{aT_e^2}$$
$$T_e \leq 0.2 \Rightarrow C_1 = 1+\frac{25(R_u\text{-}1)}{a}$$
$$T_e>1 \Rightarrow C_1 = 1$$

In which: R_u is the proportion of reactionary resistance to yield strength which is obtained by the following equation:

$$R_u = \frac{S_a}{\frac{V_y}{W}} C_m$$

a: The coefficient of the type of land which is obtained through the following table:

The type of land	I	II	III and IV
a	130	90	60

S_a is spectral acceleration to the effective main frequency of time; C_m is effective mass coefficient in the first mode which is obtained through the following table:

The number of floors	Masonry or steel flexural frame	Braced steel frame	Structure with shear masonry wall	The rest of structural systems
One or two	1	1	1	1
Three or more	0.9	0.9	0.8	1

V_y is equal to cutting the base similar to structure yield strength in the multi-line figure of force-deformation in non-linear statistic analysis; W is effective seismic load of building including dead load and 20% alive load; C_2 is correction factor for the effects of reducing the hardness and resistance of structural members on the shift caused by cyclical decline which is obtained from the following relationship:

$$T<0.7 \Rightarrow C_2 = 1+\frac{1}{800}\left(\frac{R_u-1}{T_e}\right)^2$$
$$T \geq 0.7 \Rightarrow C_2 = 1$$

After determining the target shift, the treatment of the member under forces on the yield spot and plastic region could be modeled in the Etabs. In this case, the user can consider the plasticity distribution along the element approximately by introducing a large number of joints. After determining the shift of primary purpose and the plastic joints in the model, acceptance criteria should be allocated to defined plastic joints for evaluating the structure. Acceptance criteria of beams and columns were entered into the model under the terms of improvement guidelines and type of elements and geometric characteristics of sections and the structures were analyzed.

Vulnerability assessment method of Raphael and Mir: Raphael and Mir proposed an index as to parameter of total damage according to Eq. 5 in order to assess the analytical seism of concrete and steel structures. The index values' range change from zero (no deterioration or damage) to 1 (failure or damage in whole):

$$GDP = \frac{d_R\text{-}d_Y}{d_F.d_Y} \quad (5)$$

In which d_R, d_Y and d_F are the maximum displacement of roof under earthquake, roof displacement in accordance with the primary plastic joint formation in one of the columns of the second floor to the top of the structure based on non-linear static analysis and roof displacement corresponding to collapse on the verge of one of the pillars of first floor of the structure, respectively (Eq. 4 and 6).

Newmark and Rosen Blow Damage Model: Newmark and Rosen Blow used formid ability ratio in evaluating the structural capacity as follows:

$$DI = \frac{\delta_a}{\delta_y} \quad (6)$$

In which δ_α and δ_y are the maximum displacement (floor or roof) and the amount of displacement in the moment of yield under monotonous static load, respectively (Eq. 4 and 6).

Suzan Damage Model: Suzan has defined structures' breakdown as a percentage of the maximum relative displacement between the floors according to the following relationship. The floor relative displacement is defined as the maximum displacement between two equal floors as a floor height.

$$DP = 50_{\gamma}\text{-}25 \quad (7)$$

γ is relative displacement of floor in percentage. By analyzing the experimental data on the components and small-scale structures it is known that the relative displacement between the floor <1, >4 and 6% causen on-structural components, irreparable and general damage of the building, respectively.

RESULTS AND DISCUSSION

The results are in both qualitative and quantitative assessment as follows:

The results of qualitative research of the studied buildings

Regulations of Canada (registration office building):

$$SI = A\times B\times C\times D\times E \Rightarrow SI=1\times 1.5\times 1\times 2.54\times 1.2 \Rightarrow SI = 4.572$$

$$NSI = B\times E\times F \Rightarrow NSI=1.5\times 1.2\times 6 \Rightarrow NSI=10.8$$

$$SPI = SI+NSI \Rightarrow SPI = 4.572+10.8 \Rightarrow SPI=15.372$$

According to the obtained results in this method, building is considered as the moderate priority from the perspective of vulnerability assessment. According to the index number of lower then 30, the building is low-risk in terms of the vulnerability of the earthquake.

Public library building in Bandar Abbas:

$$SI = A\times B\times C\times D\times E \Rightarrow SI=1\times 1.5\times 1\times 1.95\times 1.2$$

$$NSI = B\times E\times F \Rightarrow NSI=1.5\times 1.2\times 6 \Rightarrow NSI =10.8$$

$$SPI = SI+NSI \Rightarrow SPI = 3.51+10.8 \Rightarrow SPI =14.31$$

According to the obtained results in this method, building is considered as the moderate priority from the perspective of vulnerability assessment. According to the index number of <30, the building is low-risk in terms of the vulnerability of the earthquake.

Aria Method: Table 5 and 6 show the results of the studied buildings using Aria Method.

Registration office building:

- In MSK 7 intensity, the building is placed in the category of low damage (needs slight repair)
- In MSK 8 intensity, the building is placed in the category of low damage (needs slight repair)
- In MSK 9 intensity, the building is placed in the category of moderate damage (needs much repair)

Public library building of Bandar Abbas:

- In MSK 7 intensity, the building is placed in the category of low damage (needs slight repair)
- In MSK 8 intensity, the building is placed in the category of moderate damage (needs much repair)
- In MSK 9 intensity, the building is placed in the category of high damage (necessary repair)
- ATC-21 Method (Table 7)

In this method, registration office and public library buildings of Bandar Abbas are in the category of buildings requiring quantitative and accurate assessment since the summation of the final scores is <2.

The results of quantitative assessment of the studied buildings

Non-linear static analysis (pushover): The results of non-linear static analysis of the studied buildings in the line of calculating the target shift of buildings and also assessing the suggested joints in plan earthquakes is as Table 8 and 9.

The results of damage indices calculation

Rafaeland Mir (Public library building):

- d_R = 119.2 mm
- d_Y = 65.6 mm
- d_F = 80.4 mm

Table 5: Results of Bandar Abbas registry office damage index building using Aria Method

Intensity	Intensity 7	Intensity 8	Intensity 9
LR index	0.11	0.143	0.34

Table 6: Results of Bandar Abbas public library building damage index using Aria Method

Intensity	Intensity 7	Intensity 8	Intensity 9
LR index	0.194	0.035	0.064

Table 7: The results of damage index using ATC-21 Method (Fema-154)

Building	Final score
Registration office building	1.6
Public Library building of Bandar Abbas	1.6

Table 8: The calculated target shift of the studied buildings

	The scale of δ_t parameters							
The title of the building	C_0	C_1	C_2	S_a (g)	δ_t (mm)	V_t (kN)	D_y (mm)	V_y (kN)
Public library building of Bandar Abbas	0.86	1.05	1.00	0.680	119.2	4877.4	65.6	4069.3
Registration office building	1.18	1.13	1.02	0.825	75.9	2755.1	26.3	2222.5

Table 9: The operation of suggested plastic joints in the studied buildings

The title of the building	The operation of the joints Collapse (CP)	Life safety (Ls)	Uninterrupted use	All joints
Public library building of Bandar Abbas	810	14	24	848
Registration office building	349	3	12	364

$$GDP=\frac{d_R-d_Y}{d_F-d_Y}\Rightarrow GDP=\frac{119.2-65.6}{80.4-65.6}=3.62$$

Registration office building:

- d_R = 75.9 mm
- d_Y = 26.3 mm
- d_F = 65 mm

$$GDP=\frac{d_R-d_Y}{d_F-d_Y}\Rightarrow GDP=\frac{75.9-26.3}{65-26.3}=1.28$$

The results of assessing the buildings' vulnerability of the studied buildings using Raphael Mir index show that the public library andregistration office buildings in Bandar Abbas will be totally damaged in the case of the plan earthquake (the basic earthquake of the plan in regulations of building design against earthquake).

Suzan failure model
Public library building:

$$\Delta_1=76.4mm,\Delta_2=134.8mm,\Delta_3=168.1mm,$$
$$\delta_1=76.4mm,\quad H=4.32m\Rightarrow\gamma=\frac{67.4}{4320}\times100=1.77$$
$$\delta_2=58.4mm,\quad H=3.6m\Rightarrow\gamma=\frac{58.4}{3600}\times100=1.62$$
$$\delta_3=33.3mm,\quad H=3.6\quad\Rightarrow\gamma=\frac{33.3}{3600}\times100=0.925$$
$$DP_1=50\times1.77-25=63.5$$
$$DP_2=50\times1.62-25=56$$
$$DP_3=50\times0.925-25=21.25$$

Registration office building:

$$\Delta_1=0mm,\Delta_2=64mm$$
$$\delta_1=0mm,\ H=3.59m\Rightarrow\gamma=0$$
$$\delta_2=64mm,\ H=4.18\,m\Rightarrow\gamma=\frac{64}{4180}\times100=1.53$$
$$DP_1=0$$
$$DP_2=50\times1.53-25=51.5$$

The results of assessing the buildings' vulnerability of the studied buildings using Suzan index show that the public library and registration office buildings in Bandar Abbas will be totally damaged in the case of the plan earthquake (the basic earthquake of the plan in regulations of building design against earthquake).

Building of the registration office is in the verge of total damage and loss in Suzan Method in the case of the plan earthquake (the basic earthquake of the plan in regulations of building design against earthquake).

Newmark and Rozenblow Model
Public library building:

$$\delta_a=119.2mm,\ \ \delta_y=65.6mm\ \Rightarrow DI=\frac{119.2}{65.6}=1.82$$

Registration office building:

$$\delta_a=75.9mm,\ \ \delta_y=26.3\ mm\ \Rightarrow DI=\frac{75.9}{26.3}=2.89$$

The results of assessing the buildings' vulnerability of the studied buildings using Newmark and Rozen Blow index show that the public library and registration office buildings in Bandar Abbas will be totally damaged in the case of the plan earthquake (the basic earthquake of the plan in regulations of building design against earthquake).

CONCLUSION

Qualitative assessment results of office buildings in Bandar Abbas, especially the studied buildings using Aria method showed that the registration office building in an earthquake with an intensity of MSK 7 is placed in the category of low damage (needs slight repair) according to the results. This building is also placed in the category of low damage (needs slight repair) with the earthquake intensity of MSK 8 and is placed in the category of moderate damage (needs much repair) with the earthquake intensity of MSK 9. The public library building of Bandar Abbas in this method is placed in the category of low damage (needs slight repair) with the earthquake intensity of MSK 7 and is placed in the category of moderate damage (needs much repair) with the earthquake intensity of MSK 8 while it is placed in the category of high damage (necessary repair) with the earthquake intensity of MSK 9. The results of qualitative vulnerability assessment using ATC-21 (Fema-154) showed that registration office building of Bandar Abbas is in the category of buildings requiring quantitative and accurate assessment.

The results of the seismic vulnerability assessment were obtained using quantitative methods and non-linear static and dynamic analysis of the studied structures. In this regard, the combination of loading was used in accordance with the instructions in the seismic improvement of existing buildings (publication number 360) and ASCE-41Regulation. Assessing, the results of the shift and cutting base shows that the studied buildings did not have an appropriate resistance due to the lack of regulations in the original design in non-linear analysis and almost in all load combinations, seismic improvement publishing is collapsed. Also, the evaluating the results of the formed joints in load combinations based on the improvement publication indicate that the majority of joints are on the verge of uninterrupted use (IO) in the primary level of operation and then, without resistance and after passing of time is placed in the next levels meaning on the verge of Life Safety (LS) or Collapse (CP). As it was mentioned, the defined plastic joints in the studied buildings were on the verge of Collapse (CP) because of the inappropriate design and low capacity of designed elements in non-linear analysis in the combination of different loads. Surveying the results of proposed plastic joints show that 24 joints are on the verge of Collapse (CP) and 14 joints are in the range of Life Safety (LS) from the 848 joints in total.These joints are mainly on the first floor so that 20 joints are on the first floor, 10 on the second floor and 8 joints on the third floor which have entered non-linear range from all the proposed joints showing the poor performance of elements of the first floor in non-linear analysis. Evaluating the results of proposed plastic joints in the registry office building show that the operation of 12 joints are on the verge of Collapse (CP) from the 364 joints in the whole building. These joints are mainly on the first floor showing the poor performance of elements on this floor in non-linear analysis. Also, evaluating the registration building operation at various non-linear load combinations shows that the building beams are weakened due to the non-linear load combinations so that all the formed plastic joints are on the verge of Collapse (CP) caused by these loads.

The results of assessing the buildings' vulnerability of the studied buildings using Raphael Mir, Suzan and Newmark Rozen Blow indices show that the public library and registration office buildings in Bandar Abbas will be totally damaged in the case of the plan earthquake (the basic earthquake of the plan in regulations of building design against earthquake). Due to the weakness of elements against earthquake which is caused by the poor design, these building are totally damaged.

Registry office building is much weaker than public library building due to the structural weakness of elements caused by poor design. In many three-parameter load combinations, non-linear analysis could not be covered and was totally damaged. So, critical load combinations of this building are significantly weaker than public library building.

According to the results of the survey following suggestions are presented for increasing the efficiency of using damage indices in evaluating the seismic vulnerability to assess the concrete buildings' seismic vulnerability and identifying the strengths and weaknesses of qualitative and quantitative methods:

Evaluating the seismic vulnerability using qualitative methods shows that the major advantages of these methods are providing fast easy and without having specific evidence of buildings results that can be used without any particular problems and could be greatly taken into consideration to access the general information of buildings. But in most cases, these methods cannot show the performance of the building in dealing with earthquake. Therefore, it is recommended to select evaluating methods in accordance with the level and purpose of study.

Evaluating the qualitative assessment indices show that Aria index has more appropriate performance in presenting the assessment results using various building parameters and simple calculations. So, it is suggested to Aria method if the objective is to obtain the general information of the building against the earthquake.

The use of vulnerability assessment indices in this study showed that newmark and rosen blow usedformidability proportion in the evaluation of structural capacity. Since, this index does not include the effect of duration and frequency content of earth motion, it is concluded that there is not a satisfactory indicator. Moreover, Suzan index defined structural failure as a percentage of maximum relative displacement between the floors. Damage index based on relative maximum shift between the floors similar to damage index based on the formidability proportion does not consider the cumulative damage effects due to the repeated inelastic. Also, the relationship between the defect and the relative displacement between floors is different depending on the maximum deformation in the collapse. This difference is due to different degrees of structural plasticity, so the index is not satisfactory. The suggested relationship of Raphael and Mir has high speed and great accuracy comparing the other damage models due to the ease of choosing the determining parameters of total damage parameters. Therefore, it is suggested as an efficient relationship for the engineers.

Following the assessment carried out in this study it can be stated that the increased lateral load method is the simplest possible way for estimating the seismic responses of buildings due to the acceptable accuracy, ease of use, speed and ease of interpretation. Therefore, the suggested relationship of Rafael and Mir which is based on the increased lateral load method has the ease of choosing the determining parameters of total damage parameter, high speed and appropriate accuracy. It is obvious that in the most general status, evaluating the behavior and the operation assessment of a structure should be done based on the non-linear dynamic analyses and based on the appropriate and accurate acceleration. But excess expenses, complexity and need to knowledge and adequate background, limit the applicability of this method to all other methods.

So, it is recommended to evaluate the quantitative index operation in different buildings efficiently in another research and finally, the results be compared and the weak points in evaluating buildings with different usage be assessed.

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