Performance Evaluation and Comparison of Schools with Masonry System Treated by Braces, FRP Strips and Friction Dampers Using Fragility Curves (Case Study: Khorram Abad)

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Abstract:

Due to the importance of seismicity in the region of Iran, the improvement and retrofitting of structures has always been the focus of competent employers and engineers. Therefore, presenting and reviewing new solutions with the advancement of new technologies is of great importance. Therefore, evaluating and comparing the performance of schools with treated concrete system with braces, FRP strips and friction dampers using fragility curves in Khorramabad city can be a new step in this field considering the needs of the country, which is the basis of this research. Today, the discussion and deterioration of high importance structures is young and new in all scientific and specialized fields, so the purpose of this research is to provide indicators of deterioration, and to evaluate and compare the performance of high importance buildings such as schools, the innovative and new aspect of this research includes Obtaining fragility indices related to schools before and after seismic improvement and finally a step forward after obtaining fragility curves related to damage indices for buildings are a new and innovative thing in this research. In order to achieve the goals of this research, a three-story concrete school structure in need of improvement has been selected. Then, the investigation of possible improvement options (three improvement options: 1 with braces, 2 with friction damper, 3 using FRP in the columns) has been done in Opensees software. In the following, incremental nonlinear dynamic modeling and analysis under selected earthquake records using the recommended FEMA P695 accelerometers for co-based seismic records (5 acceleration maps for the far field and 5 acceleration maps for the near field) has been performed. Then a comparison between the fragility curves for different states has been made. From the general results of the research, it can be seen that the results obtained from the incremental nonlinear dynamic analysis indicate that this method of analysis can be very effective in evaluating the seismic performance of buildings. In this research, the behavior of the building against different earthquake intensities is shown According to the results obtained from other non-linear analyses, it can be seen that the maximum capacity obtained is in good agreement with the results of these analyzes and this method is very suitable for evaluating the behavior of buildings and ultimate capacities against earthquakes. Also, it can be a good alternative method for approximate methods such as pushover analysis to determine the performance level of the building and to determine the behavior of the building.

Keywords: Fragility Curves, Concrete Structure, FRP Strips, Frication Dampers, Seismic Rehabilitation .

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1. Introduction

The location of Iran in one of the seismic areas of the world and the possibility of destructive earthquakes in all parts of the country has made Iran important from the point of view of seismicity, the fact that Iran is located on the global earthquake belt and using the experiences of other earthquake-prone and successful countries in Organizing urban affairs and strengthening cities in earthquake-prone areas seems to be more sensitive and important than past. Common earthquake-resistant systems often experience inelastic behavior throughout the structure during a large earthquake, which ultimately results in residual deformation and distributed damage in the structure, in such a way that the repair of these damages is not cost-effective and sometimes It leads to the complete destruction of the structure.

So far, many researches and studies have been done in the field of how to strengthen the buildings built in different countries and remarkable results have been obtained. In general, retrofitting conventional buildings is common in the following cases:

-Damaged buildings during the earthquake.

-Buildings whose usage has been changed.

-Buildings that do not have enough resistance due to changes in regulations.

-Buildings on which additional stories are to be built.

-Buildings in which signs of weakness have appeared in the form of cracks.

The purpose of retrofitting is to achieve the expected conditions of the building at the desired level of operation for a specific intensity of the ground shaking, and to achieve this goal, any corrective measures include hardening or retrofitting the building, adding local components to remove irregularities, closing the building components to each other, reducing the earthquake demand in the building through the method of isolating or absorbing energy or reducing the height or mass of the building, which can be used in the form of retrofitting methods to achieve the stability and resistance of the building against the lateral load caused by the earthquake as a technique. Risk reduction methods were considered. It is obvious that the variety of buildings as well as the variety of retrofitting purposes makes the retrofitting methods and techniques different. Buildings damaged by earthquakes or buildings that are recognized as weak should be repaired and strengthened in such a way that their initial resistance is restored or even increased in order to withstand future earthquakes. Repaired buildings must meet the requirements of regulations. In any case, the repair or seismic strengthening of a building may be very expensive. The final decision on whether to repair and retrofit, and if so, how, requires a comprehensive economic review. Nowadays, the use of advanced composite materials in building engineering to reinforce and strengthen buildings is increasing. Composite materials are made from the combination of fiber and matrix, the fibers are usually made of carbon, glass, and aramid, and the matrix is from the family of polymer matrices such as epoxy. Due to their diversity and very good properties, composite materials will play a decisive role in the near future for arming strategic buildings, especially masonry buildings and strengthening buildings implemented in earthquake-prone areas.

Due to the fact that most of the existing buildings in the country are built based on the 2800 standard and in order to ensure the level of life safety performance under the earthquake, for this reason, after an earthquake at that level, these buildings are damaged and destroyed, and in order to reuse the structure, it is necessary to spend time. And the high cost is due to the extent of the damage in the structure, and therefore considering that until now the analysis of schools has been up to the stage of risk analysis and obtaining fragility curves, so it is necessary to take a step beyond the current discussions. Therefore, this issue makes checking the possibility of damage of structures to be very essential. Due to the large number of buildings such as schools, special attention should be paid to the discussion of deterioration indicators in these important structures. Schools are one of the crowded places and are considered to be structurally important, so this research is focused on evaluating and comparing the performance of schools with improved concrete system with braces, Fiber Reinforced Polymer (FRP) strips and friction dampers by using fragility curves in Khorramabad city.

In recent years, a lot of progress has been made in the field of earthquake engineering and structure design, so that today it is possible to design earthquake-resistant structures with more confidence. However, many concrete structures fail due to the following reasons: 1) calculation errors, 2) mistakes in construction and implementation, 3) weakness of old regulations, 4) change of use of the structure and operating loads on the structure, 5) corrosion and rusting of armatures, etc. They do not satisfy the requirements of the new regulations, so it is necessary to provide methods of retrofitting, improvement and repair of such structures. One of the effective and efficient methods in strengthening concrete buildings is strengthening columns by using coating. This action increases the stiffness, strength and ductility of the column. Recent factors increase the safety of the structure against earthquakes. In 1988, Mr. Katsumata presented a new method to repair and strengthen concrete columns in Japan. This method consists of: wrapping special plastic fibers around the concrete column and using a special polyester glue to integrate the fibers and connect it to the concrete column. What distinguishes the use of composites in strengthening and repairing structures is that these materials can be designed in such a way as to make the structure behave as needed. Because the function and resistance of these materials is only in the direction of their fibers and they can be designed in such a way that they show resistance only in the required direction [1].

In the last two decades, the use of FRP composites for strengthening various structural components has grown increasingly. The effects of using composite sheets for enclosing concrete in reinforced concrete columns are very impressive and effective, so that a special effort has been made to strengthen this part of the structure with FRP. Based on this, a lot of research has been done in order to determine the stress-strain curve and develop a mathematical model to explain and predict the behavior of confined concrete. In 1988, Mander and his colleagues presented a relationship for the confinement of concrete by transverse steel [2], which is the basis of many models presented for the stress-strain curve of concrete confined by composite [2]. In order to make this model as accurate as possible for entrapment by composites, researchers tried to provide new relationships [3].

In their article, Azmoun et al. (2019) investigated the presentation of a new method for shear strengthening of reinforced concrete beams with Carbon Fiber Reinforced Polymer (CFRP). To achieve the goals of the research, one concrete beam specimen was used as a witness and six concrete beam specimens were reinforced using carbon fibers with different arrangements. All specimen is made with the same reinforcement and concrete. The specimen was subjected to two-point loading in the structural laboratory of Ferdowsi University of Mashhad, and the shear failure in the reinforced concrete beams was delayed and prevented to some extent, and in some beams, flexural cracking and flexural shear failure occurred. In addition, the strength of concrete beams reinforced with carbon fibers has also increased significantly [4].

In their article, Delfani et al. (2017) investigated the nonlinear behavior of a reinforced concrete building retrofitted with CFRP under progressive failure using the alternative path method. In this research, the progressive damage analysis method is briefly stated and then the behavior of a seven-story reinforced concrete structure consisting of a special frame system designed against seismic forces under progressive damage according to UFC 4 023 03 regulations based on the method The alternative path is evaluated using SAP software. It can be seen that the structure is not able to meet UFC requirements. Therefore, the weak beams were reinforced in bending with polymers armed with carbon fibers. The analysis results show that the adopted method has significantly improved the continuity and strength in the beams adjacent to the removed column and the distribution of plastic joints is satisfactory. As a result, the damage remains localized [5].

In their article, Sangi et al. (2019) investigated the numerical evaluation of the failure behavior of notched concrete beams reinforced with CFRP sheets. Using the finite element method and non-linear static analysis, the bearing capacity of the specimen, the separation of the sheet, the growth and opening of the crack have been evaluated. First, in order to evaluate the accuracy of the modeling, the results obtained with the data obtained from the existing laboratory work were compared, and after ensuring the correctness of the modeling, the effect of changing different parameters such as sheet thickness, concrete mechanical characteristics, initial crack length and adhesive strength was investigated. The results show that the crack opening load diagrams have two maximum load points, the first and second maximum points increase with the increase of concrete strength, adhesive strength and sheet thickness, and due to the increase in the initial crack length, the first maximum point decreases. while the second maximum point remains almost unchanged [6].

Eshaghian and Karamati (2016) in their article investigated the experimental and numerical investigation of the Glass Fiber Reinforced Polymer (GFRP) concrete composite profile column enclosed with CFRP. A new type of composite column consisting of composite profile, concrete and FRP polymer fibers has been presented and investigated by laboratory test and numerical model. The purpose of this research is to design a composite concrete column without using steel materials but with a relatively low weight. Common problems of concrete failure due to expansion and corrosion of reinforcing members are inevitable. This goal can be achieved by using I-shaped FRP composite structural sections instead of reinforcing steel in concrete. The composite column surrounds the composite profile using an FRP cylinder with glass fibers and then the section is filled with concrete. The GFRP cylinder acts as an in-situ form, in addition to providing concrete confinement. Therefore, three columns have been tested in the laboratory program under monotonic axial compressive loading. The final capacity of each of the tested composite columns has been compared with the theoretical capacity of the numerical model proposed by ANSYS program, the results of the laboratory specimen and numerical analysis have been in good agreement [7].

Amiri et al. (2009) in their article investigated the seismic improvement of reinforced concrete buildings reinforced with CFRP fibers. In this regard, for further research in the improvement of existing buildings, three symmetric concrete buildings of 4, 7 and 10 stories were evaluated according to the criteria of the improvement instructions, with the aim of optimal improvement using the non-linear static analysis method by SAP software. In the end, it was found that reinforcing concrete columns with FRP increases the strength and especially the cumulatively of the building [8].

Babaei and Rouhani have investigated the performance of FRP in an article titled comparing new methods of strengthening concrete beams with old methods. In this article, he compares the new method of strengthening concrete beams with FRP rebars that are used near the surface with the common method of using FRP sheets according to the results of laboratory research. In the end, it was determined that the strength increase in the Near Surface Mount (NSM) method is more than the Externally Bonded Reinforcement (EBR) method and the dominant mechanism is from separation to beam failure with FRP yielding [9].

In his work, Andalib has investigated the modeling of the effect of FRP composite fibers on the strengthening of reinforced concrete columns using the finite element method. He has investigated the effect of changing the local strengthening parameters of the column and finding the optimal relative length of the screw from the foot of the column for bending strengthening. His goal in this research is to investigate the behavior of inefficient columns and the effect of strengthening the plastic hinge area with glass and carbon fibers on the performance of these columns. Comparing the results of the specimen that were loaded in the laboratory with the sample analyzed by the software shows that the results obtained from the finite element model have acceptable results compared to the laboratory results [12].

Seismic fragility curves were presented for the first-time using Monte Carlo simulation by Kevorkian et al. (1996). They showed that the intensity of the earthquake, the frequency content and the duration of the earthquake are among the important parameters that have a great impact on the response rate of structures and the level of damage. For this reason, these parameters are considered in obtaining fragility curves [14].

Incremental dynamic analysis (required by this methodology) today is one of the valid nonlinear dynamics analyzes that Vamatsikos and Cornell (2002) proposed, in this regard, by selecting several existing acceleration maps that gradually increase their intensities by applying coefficients to bring the structures to the point of failure [15].

In their work, Ganidi and colleagues investigated the control of nearby buildings using dampers. According to them, the seismic control of nearby buildings has attracted significant attention in recent years due to two issues: 1) To control the response of two buildings simultaneously by a single control device. and 2) to reduce the possibility of interaction between two buildings [32]. In their work, Morodi et al. (2004) investigated the seismic effects of dampers for different ground motion parameters. In this article, the effectiveness of dampers in controlling the seismic response of structures and the effect of different ground motion parameters on seismic effects have been investigated [33]. In his work, Nateghi has investigated the effect of dampers on the seismic response of building frames with uncertain structural characteristics. In this research, in order to investigate the possible

response of the earthquake-resistant steel frame equipped with a damper, it has been studied in the possibility of structural failure through cumulative damage for the structure [34].
The formulation of multi-degree-of-freedom equations for adjacent multi-story buildings connected with earthquake dampers has been presented in another study. The time history of the El Centro earthquake has been used for the dynamic analysis of the system over time [36]. Masoumi and Beheshti (2014) also in an article entitled "A systematic approach to evaluate the failure probability of medium bending frame steel structures based on intensity and demand criteria" investigated how to achieve two types of methods for producing fragility curves and the combined method resulting from these two methods [37].
In another study, the effect of MR dampers in reducing the seismic response of adjacent multi-story buildings in three active, passive and semi-active control strategies has been investigated [38]. Meridani and Khodayari (2013) also investigated an efficient approach in evaluating the damage levels of structures in different seismic intensities using Incremental Dynamic Analysis curves [39]. Guin Chen and his colleagues (2015), in research, investigated the effect of unbounding materials on the mechanical behavior of all-steel buckling-resistant braces [40].

2. Methods

With all these aspects, in this research, the role of the improvements made in the case study schools of a school with masonry will be investigated. In this study, the damage indicators before and after seismic improvement are studied by obtaining fragility curves. Therefore, it is considered to obtain comparative charts related to different states of damage indicators and to see these indicators in the possibility of school building damage. In this regard, the steps of conducting this research will be as follows: first, appropriate verification is done with a selected article that is modeled in nonlinear software, and the degree of compatibility with the desired article is measured. Then, a three-story structure is examined and compared in two states before and after improvement with FRP, dampers and braces. Incremental nonlinear dynamic modeling and analysis (IDA) in OpenSees software under selected earthquake records using FEMA P695 recommended accelerometers for co-based seismic records (5 accelerometers for the far domain and 5 accelerometers for the near domain) with SeismoSignal software is done.

2-1- Validation

For the purpose of validation, the article of Junaid Akbar, Naveed Ahmad, Muhammad Rizwan, Sairash Javed, and Bashir Alam (2020) was used. In this article, a reinforced two-story building masonry structure has been tested and the IDA curve has been obtained for it. Therefore, in this research, the same structure is modeled in Opensees software for accuracy, and for the accuracy of the model, a comparison is made between the curves obtained from incremental nonlinear dynamic analysis, so that a comparison can be made between the results. The specifications of the modeled structure based on the reference article are as follows. They have used a seismic table for laboratory testing. A wall is equated with an equivalent frame made of vertical elements (columns) and horizontal elements (beams) and rigid connections. Vertical elements resist all dead and live loads and lateral forces, and horizontal members; The frontal beams will be responsible for the transfer of forces. Bases and beams are connected by rigid regions and each element is modeled using the correct rules. In such a method, a number of possible ruptures are considered in each element, such as failure due to horizontal sliding, diagonal shear failure, and flexural shear failure of the walls using equivalent beam and column elements and will be modeled as a flexural frame. Equivalent frame modeling has been done by OpenSees software in this research and by defining the characteristics of resistance and hardness of building materials. In other words, in this article, experimental and numerical studies have been done on the frames of two-story reinforced concrete (RC) masonry materials. The design philosophy of the retrofitting solution is to allow the beam-column members to deform inelastically and dissipate seismic energy. Seismic tests have been conducted on three two-story RC frame models in a reduced scale of 1:3. The focus of the experimental study has been to understand the seismic behavior of both built and retrofitted models and to obtain the characteristics of the seismic response, i.e., the lateral capacity curves and the time history of the location change of the model response. For the numerical model in this article, SeismoStruct finite element software was used to develop numerical models, which were calibrated with experimental data in simulating the time history response of the roof of the structure and in predicting the maximum displacement of the roof and the maximum shear force of the foundation. In addition, finite element-based numerical models were scaled to multiple intensity levels for a set of natural spectrum accelerators to perform incremental dynamic analysis.

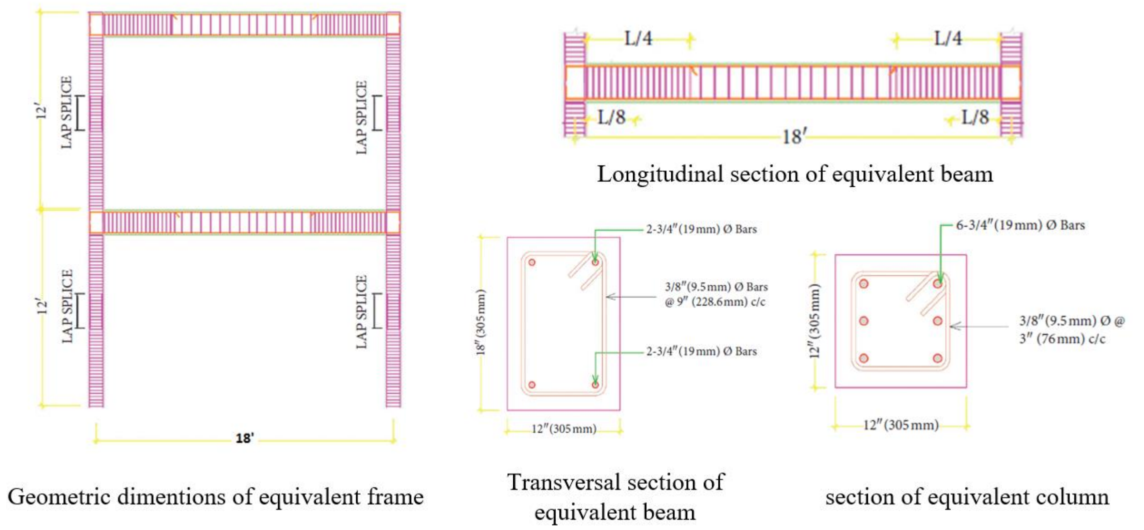

Fig. 1. Geometric details of the two-story structure considered in the reference article [24]

Table 1. Loading of the studied building [24]

Total (ton)	Live Load (ton)	Dead Load (ton)		Story
		Roof (ton)	Wall (ton)	
117.17	2.96	40.70	73.51	Ground Floor
116.86	2.22	37.00	77.64	First Floor
234.02	5.18	77.70	151.14	Total

Table 2. Characteristics of the desired wall materials [24]

Compressive Strength	Tensile Strength	Elastic Modulus	Poisson's ratio
5MPa	$0.15f'_m$	$400f'_m$	0.2

Fig. 2. The structure tested in the laboratory according to the reference article [24]

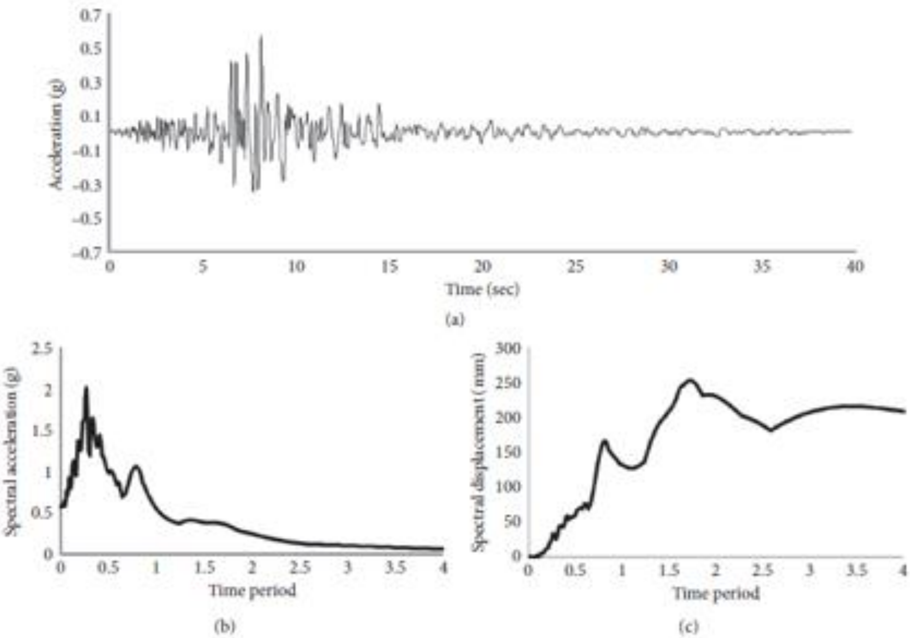

Fig. 3. The earthquake used in the reference article (Northridge 1994) and the obtained response spectra [24]

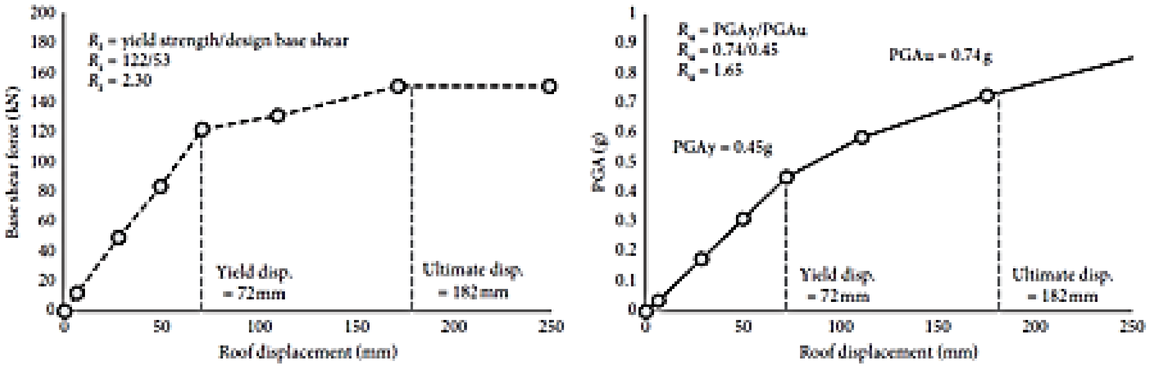

Fig. 4. The IDA curve obtained based on the response of the structure for the mentioned earthquake based on the article [24]

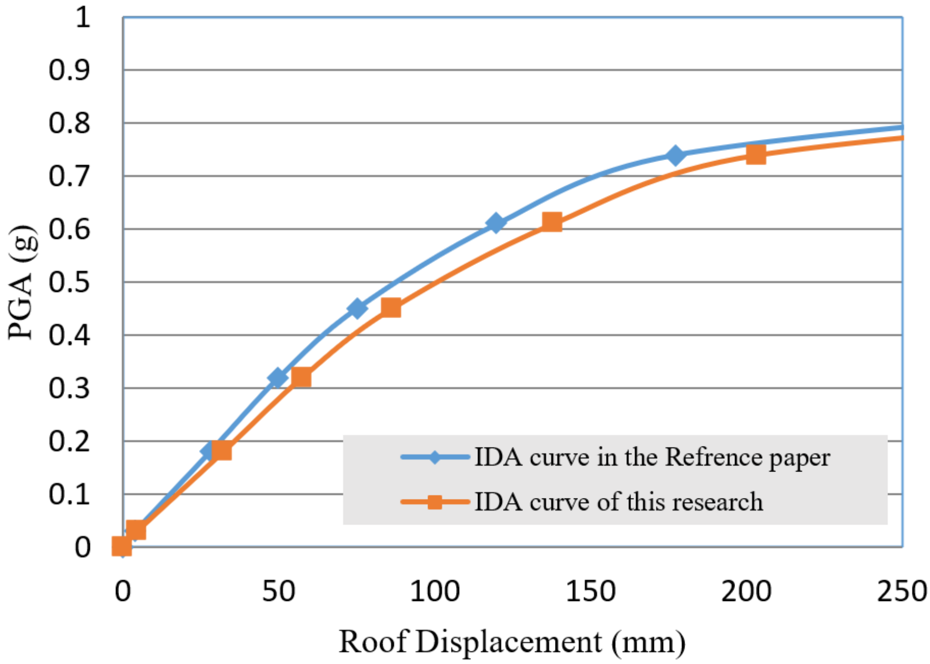

Fig. 5. Comparison of the IDA curve obtained in the model of this research and the reference article

As can be seen, there is a good match between the model of this research and the reference article, and the error of the result is less than 15%, which is acceptable.

2-2- Selection of Accelerograms

As mentioned in the previous chapters, the first step in the functional evaluation process of drawing IDA curves is to prepare a set of earthquake accelerograms, so that this set represents the seismicity of the desired area. In fact, if a sufficient number of earthquakes accelerograms have been recorded in the desired area, that collection will be used, otherwise, similar accelerometers of the region that are taken from the PEER site can be used. Therefore, in the first step, accelerograms should be selected that match the almost similar conditions of the region in terms of the fault mechanism, the distance to the desired site, and the magnitude of the earthquake. Considering the flaws in the accelero-grams recorded in Iran and the fact that there are doubts about their accuracy, therefore, in this research, in order to reduce the error caused by the selection of accelerograms, the number of 10 accelerograms recommended by FEMA P695 [53] has been used. The hypotheses for the selection of these accelerograms are given in the introduced reference. Also, the specifications of these accelerograms are summarized in the table below. It should be noted that in this article, each of these 10 accelerograms are scaled according to the spectral acceleration of each at 5% damping and the periodicity of the first mode of the structure Sa (0.05, T1). For this purpose, SeismoSignal and Excel software have been used in this article. In this way, first the spectral acceleration of each of the records is brought to the number one, and then according to the appendix modeling and analysis file of each of the selected records, the scale is from 0.1g to the limit of structural failure (which here is approximately 1.5g).

The diagram of the accelerograms used in the table 3 is given in figure 6, which was drawn using SeismoSignal software.

Table 3. Characteristics of 10 earthquakes used for the far and near fault domains introduced in FEMA p695 [53]

No	earthquake	Station name	Occurance date	scale	distance	Soil type	Fault type	PGA
1	Northridge	Beverly Hills - Mulhol-USC	1994	6.7	17.2	D	Thrust	0.52
2	Duzce, Turkey	Bolu-ERD	1999	7.1	12.4	D	Thrust	0.48
3	Hector Mine	Hector-SCSN	1999	7.1	12	D	Strike-slip	0.82
4	Imperial Valley	Delta-ENAMUCSD	1979	6.5	11.7	C	Strike-slip	0.34
5	Kobe, Japan	Nishi-Akashi-CUE	1995	6.9	22	D	Strike-slip	0.35
6	Kocaeli, Turkey	Duzce-ERD	1999	7.5	12.5	D	Strike-slip	0.38
7	Landers	Yermo Fire Station-CDMG	1992	7.3	7.1	C	Strike-slip	0.51
8	Landers	Coolwater-SCE	1992	7.3	19.2	D	Strike-slip	0.24
9	Loma Prieta	Capitola-CDMG	1989	6.9	15.4	D	Strike-slip	0.36
10	Manjil, Iran	Abbar-BHRC	1990	7.4	13.5	C	Strike-slip	0.22

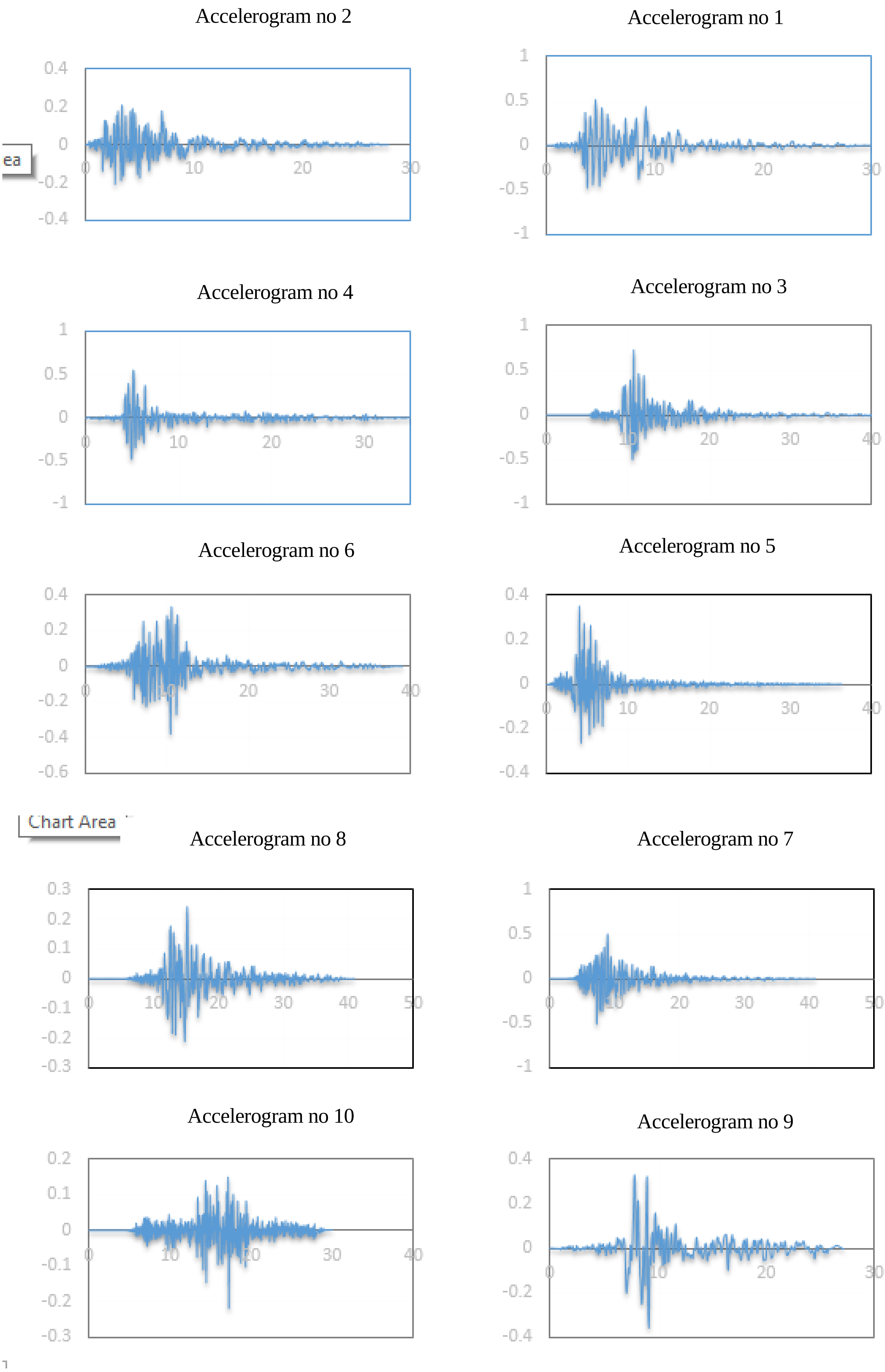

Fig. 6. Diagram of used accelerograms [53]

2-3- Introducing of the Investigated Models

In this research, a three-story structure was used. The investigated structure has a three-meter opening and a height of 3.2 meters. In fact, three structural models are considered for this project. Because this structure is modeled with three different proposed modes (1 mode with bracing, 2 frictions damper, 3 use of FRP in columns) and before and after applying the improvement options in Opensees software to perform analysis, Incremental nonlinear dynamics is performed under selected earthquake records. Then, the risk analysis of the investigated area is evaluated. Finally, the fragility curves related to the improved school building are obtained for different options before and after the improvement for the recommended functional levels of FEMA. In order to achieve reality-based results, the design of the structures has been done in OpenSees software based on the two-dimensional model with the plan shown below, and then one of the side frames as a representative of the structures has been subjected to further analysis. This causes factors such as biaxial bending to be considered in the design of the columns. On the other hand, in the design of the structures, both resistance criteria and displacement between floors, as well as strong column and weak beam criteria have been taken into account. The use of the mentioned buildings is assumed to be school-type and of high importance. The materials used are AIII steel with a yield strength of 4000 kg / cm2 for reinforcements and concrete with a compressive strength of 210 kg / cm2 and an elasticity modulus of 2.05×10^6. According to the classification of the design code, the soil type of the site is assumed to be type III with a shear wave speed of $360\ \frac{m}{s} < V_s < 760\ \frac{m}{s}$. The location of the project is in Khorramabad city and due to the high risk, it is equivalent to the base acceleration of the plan equal to 0.3g. It is also assumed that the nearest distance from the seismic source is more than 15 kilometers. Equivalent static analysis has been used for the initial design and the participation percentage of live load has been selected as 20% according to the code of building design against earthquake force. In this regard, the number of 10 acceleration maps of the area near and far from the fault, which are in accordance with the construction conditions of the investigated structure, are used, which are extracted from the PEER site, and the specifications of each are given below.

Table 4. Structural loading

Structure loading	
live distributed load	Roof dead distributed load
200 Kg/m2	500 Kg/m2

Table 5. Specifications of materials used in the project

Concrete materials of category C25.		**ST37 type steel materials**	
M ،Mass per unit volume.	0.255 ton/m^3	M, Mass per unit volume.	0.8 ton/m^3
W ،Weight per volume.	2.5 ton/m^3	W ،Weight per volume.	7.85 ton/m^3
E ،Elasticity Modulus	$2.5*10^6$ ton/m^3	E ،Elasticity modulus	$2.1*10^7$ ton/m^3
Concrete compressive f'_C ،strength	2500 ton/m^2	F_y ،Steel yield stress	24000 ton/m^2
longitudinal bar yield f_y ،stress	40000 ton/m^2	،F_u, Steel ultimate strength	37000 ton/m^2

f_{ys} ،stirrup yield stress	30000 ton/m^2		

In this project, the specifications of the concrete materials used in the wall and roof are of the same type. In the implementation, due to the simultaneity of concreting the roof and wall, the same type of concrete is usually used. The structures have a floor height of three meters and the dimensions of the structure in the plan as well as the loading of the structure as described in the following forms:

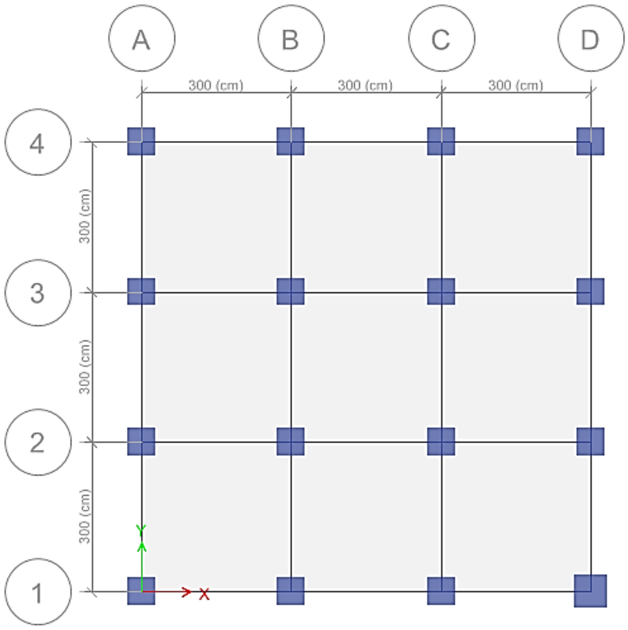

Fig. 7. Overview of the plan of all four structures modeled in the software

It should be noted that the modeling of the unreinforced three-story structure in ITBS software is only for the initial design and obtaining the initial sections, and the improved states with dampers and two layers of FRP tape for the columns, as well as the reinforced state with braces, are applied in the improvement models in OpenSees. Therefore, the basic sections of beams and columns for the structures are as follows, and in the following, an overview of the frames designed in the ITBS software environment for both structures will be given.

Table 6. Allocated sections for selected side structural frames for all four structures

Selected sections of regular three-story structure		
Beam section	column section	Floors 1-3
B 300*300 8PHI18	Col 300*300 20PHI18	

Table 7. Characteristics of used damper

Structure type	(N/m) K_d hardness	(N.S/m) C_d damping	Additional damping ratio due to the damper.
3Stories Structures	1868.77e+06	37.38e+06	5%

3. Results

3-1- Results of incremental dynamic analysis (IDA) for the vertical elements of selected earthquakes

The response of a structure underground movements can be estimated with appropriate accuracy by performing dynamic time history analysis. One of the most important drawbacks of applying nonlinear dynamic analysis is the sensitivity of response to selective accelerograms. Providing incremental dynamic analyzes and estimating responses based on the application of probabilistic relationships has compensated for this weakness in practice. The results of IDA analysis obtained from this method for the vertical element of selected earthquakes are shown in figures (8,9,10 and 11).

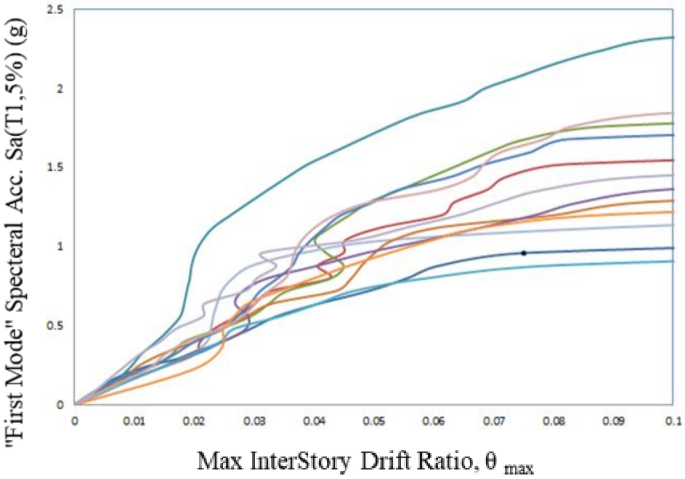

Fig. 8. The results of the IDA analysis of the three-story concrete building without retrofitting

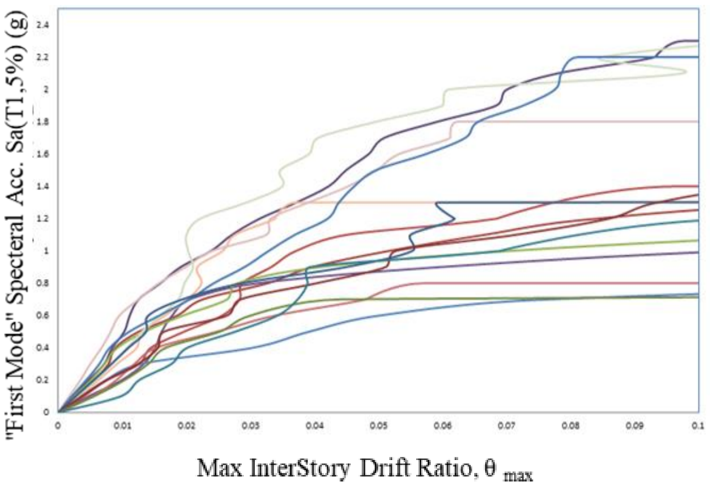

Fig. 9. The results of the IDA analysis of the three-story concrete building in the retrofitting mode with friction damper

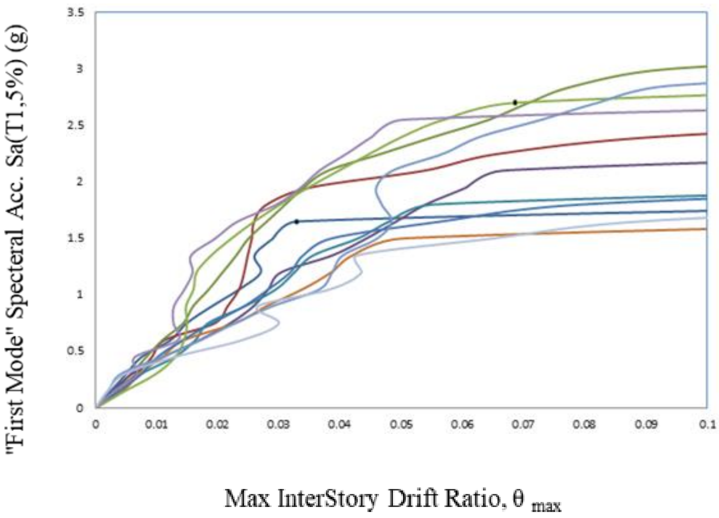

Fig. 10. The results of IDA analysis of the three-story concrete building in the reinforcement mode with braces

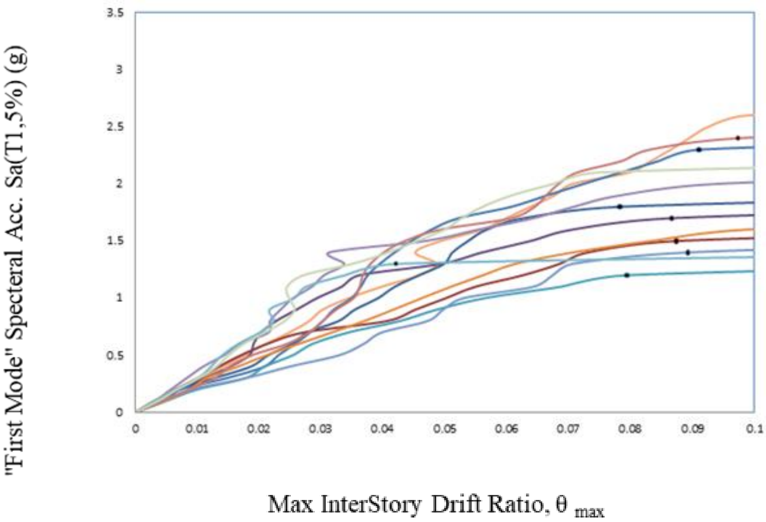

Fig. 11. The results of the IDA analysis of the three-story concrete building in the state of strengthening with FRP wraps

In the figure 12, a comparison is made between the summary of the curves obtained from the results of the IDA analysis for all four modeled buildings. As can be seen, more rigid buildings become horizontal at a higher Sa level, and in other words, their curve is higher.

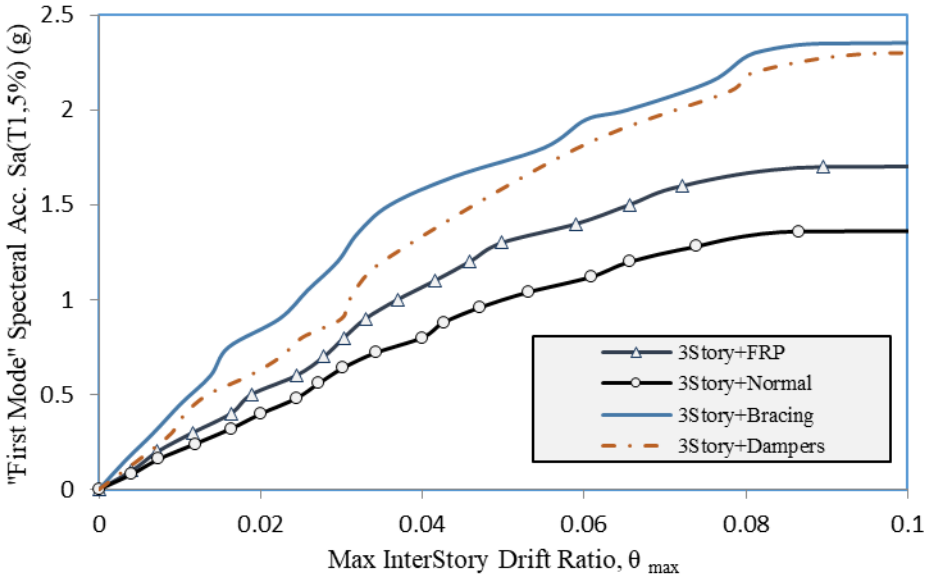

Fig. 12. Comparison of the results of IDA analysis for all four buildings

3.2. Obtaining damage curves

In order to extract the probability of occurrence of limit states from the outputs of IDA analysis, graphs known as fragility curves are used, and to draw these graphs, the IM seismic intensity corresponding to the occurrence of the desired limit states is arranged in descending order for all accelerograms.Using the ordered values, the probability of the occurrence of the limit state in the structure is calculated for values smaller than or equal to a desired IM value, which is a cumulative probability, and its graph is drawn against the IM value. Using this diagram, it can be said that for each IM level, the probability of occurrence of the limit state is, provided that the value of IM is limited to the desired level. Calculating the intensity criteria for the limit state of non-stop usability is also easy and it is enough to calculate all the intensity criteria in which DM=θmax=2% is created. This value is the first sign of the occurrence of the limit state in the curve. Considering the limit state of CP destruction threshold, fragility curves related to structures can be drawn. It should be noted that according to FEMA 350 guidelines, the destruction limit state Collapse Prevention is considered to be the point equivalent to 20% of the initial average slope, which corresponds to the starting point of horizontalization of the IDA curves. Fragility curves are obtained and their comparison is drawn in figures (13,14,15,16,17 and 18).

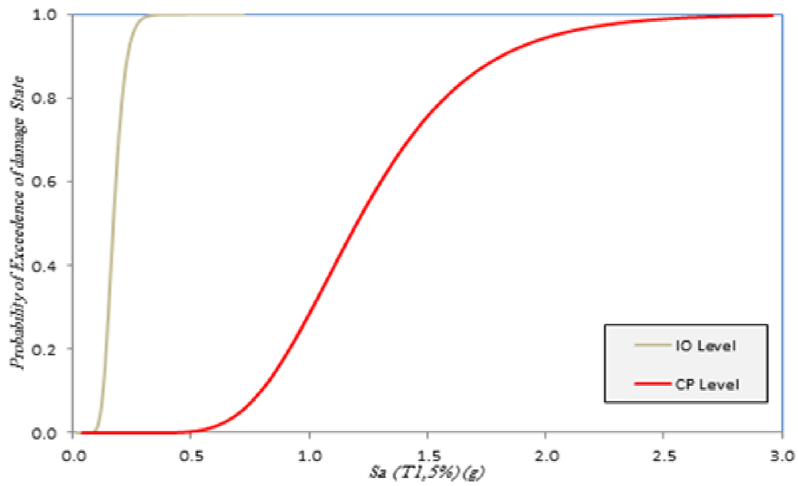

Fig. 13. summarizes the resulting fragility curves for Immidiate Occupancy and Collapse Prevention damage level for the building without retrofitting

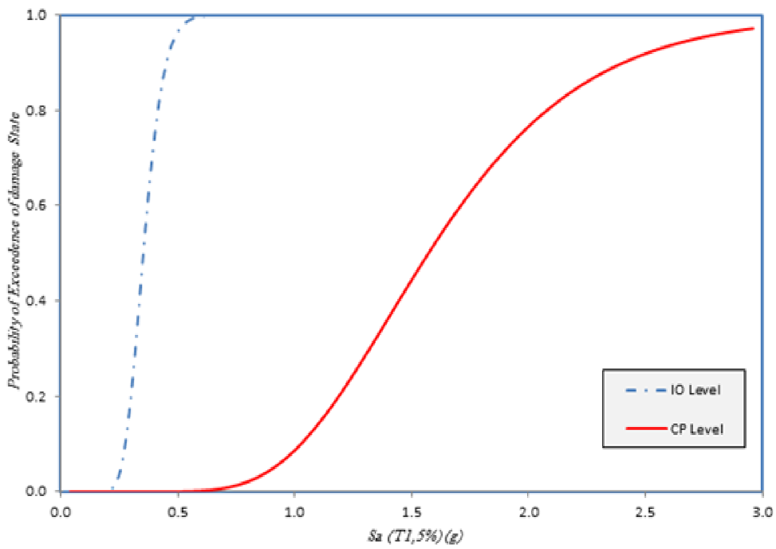

Fig. 14. Summary of the resulting fragility curves for the immediate Occupancy and collapse prevention damage levels for the building reinforced with braces

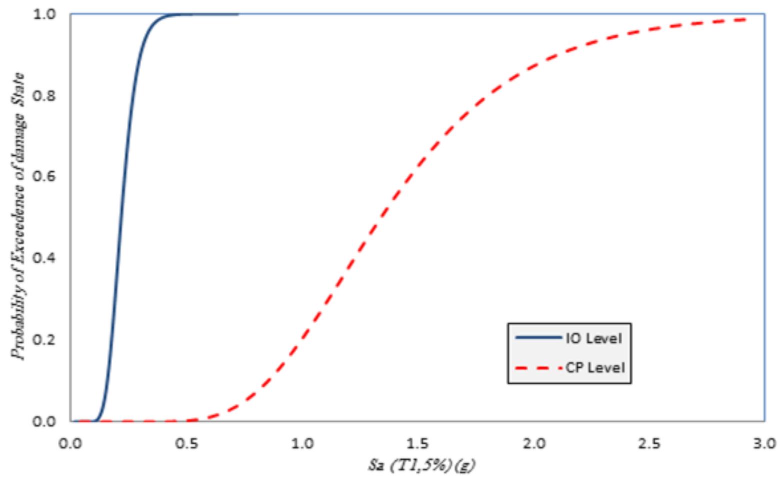

Fig. 15. summarizes the resulting fragility curves for the IO and CP damage levels for the FRP-reinforced building

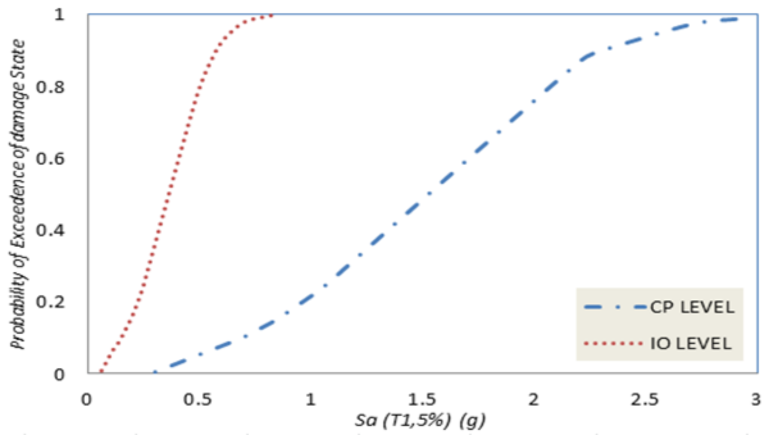

Fig. 16. Summary of the resulting fragility curves for the IO and CP damage levels for the building retrofitted with dampers

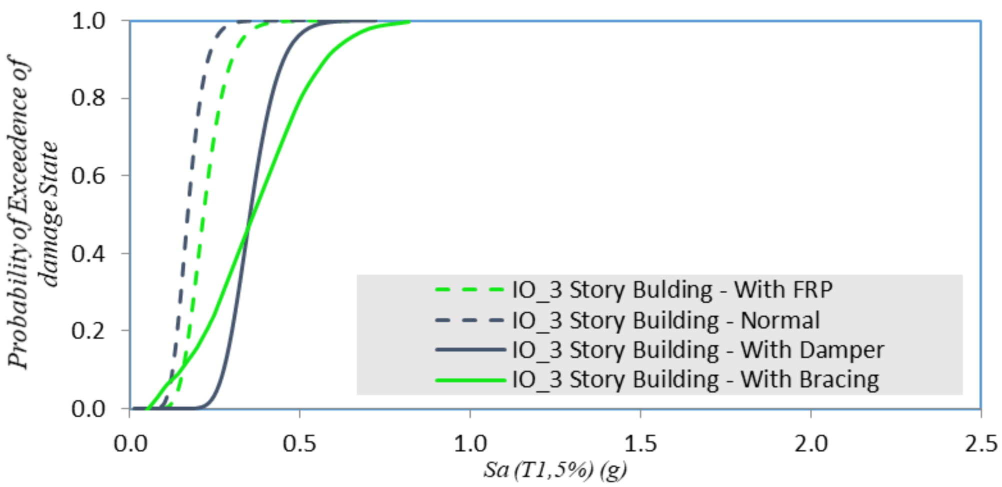

Fig. 17. Comparison of fragility curves resulting from IDA curves for IO damage level for four buildings

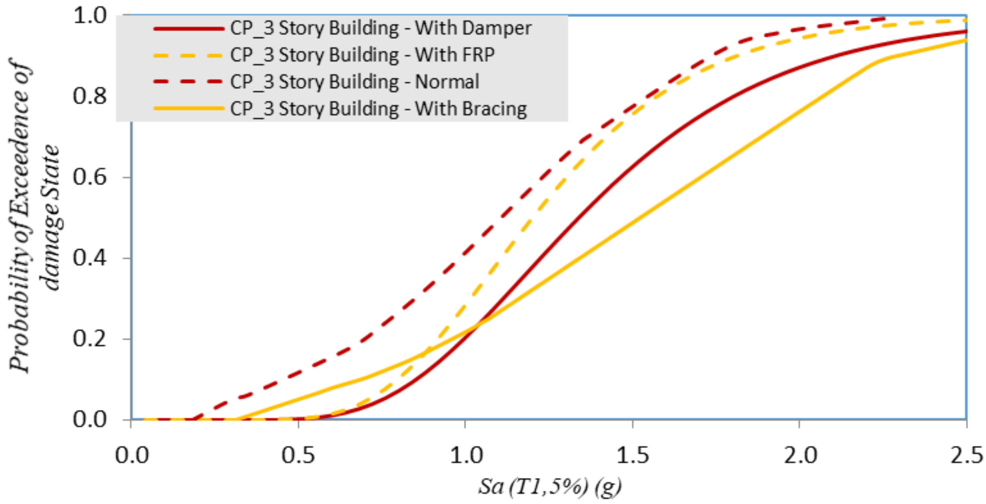

Fig. 18. Comparison of fragility curves resulting from IDA curves for CP damage level for four buildings

In the above forms, the fragility curves obtained by using the results of IDA analysis and using the log-normal probability density function relationship can be seen. These curves were obtained for two IO performance levels and CP performance level for all 4 buildings and were compared separately.

4. The conclusion

From the general results of the research, it can be seen that the results obtained from the IDA analysis indicate that this method of analysis can be very effective in evaluating the seismic performance of buildings. According to the results obtained from other non-linear analyses, it can be seen that the maximum capacity obtained is in good agreement with the results of these analyzes and this method is very suitable for evaluating the behavior of buildings and ultimate capacities against earthquakes. Also, as observed, there is a good match between the model of this research and the reference article, and the error of the result is less than 15% and is acceptable. It can be a good alternative to approximate methods such as pushover analysis in order to determine the performance level of the building and to determine the building behavior.

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