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Presenting a Neural Network-Based Hybrid Method for ADAS Damper Optimization in Absorption of Earthquake Energy

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Abstract

Improving buildings' behaviour by reducing lateral loads' effect is a new topic in earthquake engineering. It is based on reducing the energy applied to the structure through its depreciation. Structures can consume much energy in an earthquake due to their ductility. The use of energy-consuming systems in buildings allows structural members to remain resilient. Therefore, this research investigates a combined neural network-based method for optimizing Added Damper and Stiffness (ADAS) dampers in steel buildings. Thus, the seismic behaviour of each is addressed by modelling a 15-story steel structure with steel bracing in at least four reinforcement modes with ADAS damper. The selection criterion of these structures is the study of high-rise structures, and the study of finding the optimal state of reinforcement with dampers is discussed. Incremental Dynamic Analysis (IDA) using at least ten accelerograms is used in this regard. In this regard, Etabs software is used for the initial design of structures, nonlinear analysis, and optimization of OpenSees and Matlab software. It was observed that in different types of dampers arrangement, different behaviour is observed in structures. Also, the type of mirrors if due to the different hardness and performance of each damper, also led to a change in the behaviour of the structures modelled in this study. Of course, what was observed so that it is not possible to say with certainty which mode leads to better performance in structures because the performance of all four types of attenuators is very close to each other. Still, it can be said that all dampers can be considered suitable improvement options according to the employer's conditions in terms of executive capability. Dampers increase the relative displacement of the floors by improving the structure's stiffness, thereby reducing structural and non-structural damage. Triangular Added Damper and Stiffness (TADAS) and ADAS dampers have good seismic behaviour, can withstand a large number of cycles, and can absorb a large amount of earthquake energy without loss of stiffness and resistance. The use of dampers in determining the overall and local response of the sample structures under the earthquake record will positively affect the reinforcement of the structures.

Keywords: Neural network, Optimization, ADAS damper, TADAS damper, Absorbing energy.

1 | Introduction

One of the natural hazard that led to damage in structure and may loos of life is earthquake. Keep the structures safe against earthquake is a hot topic nowadays in civil engineering. We designed structures in order to be safe under strong ground motion.

Also our new buildings need to be strengthened so nowadays using a system that lead to damp the energy of earthquake have been proposed beside resistant designed. Using the structure that control and reduce structural vibration is a topic that researcher deal with it [1]. According to some application methods, we can number vibration control system to passive, active, semi control and hybrid systems. According to the above system the passive control doesn't need input energy, and based on the response of the structural the control forces are obtained [1].

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The active control systems need a significant power source. These systems balance the seismic force [2]. The best features of passive and active control systems are hybrid control system because this system by using dampers and isolators together it can have a better behavior in an earthquake [2]. The semi-active control system has reliability similar to passive control systems and it has flexibility like active control systems [3].

The design process of dampers in concrete or steel structures is subject to various design variables and parameters based on their system type, so since in the standard methods to achieve an optimal value in the design parameters of a structure equipped with a damper in the software such as SAP and Etabs, static or dynamic nonlinear analyzes must be used several times, and because these analytical methods will take a relatively long time to obtain an optimal value. As a result, we considered it necessary to use a hybrid method based on neural networks. And by using the capacities of optimization algorithms, we will investigate the effect of optimizing Added Damper and Stiffness (ADAS) damper design parameters and conduct research in this field to find a quick, easy and low-error solution to achieve the optimal ADAS damper parameters in steel structures.

There have been many articles on structural engineering and earthquakes, and many structural control concepts have been mentioned in each of these scientific works. One of the procedure of seismic control of the structure is the passive control way to reduce the vibration caused by external forces such as earthquakes. This method uses dampers that absorb and dissipate a percentage of the energy entering the structure with different mechanisms. In passive systems, the damping effect is applied without an external force to the damper system. Researchers have come up with various ideas for making dampers in recent decades. Still, the concept of using yielding steel sheets to improve the seismic behaviour of structures started in 1978 in a nuclear power plant in the United States, and Considerable progress has been made in this field [4].

In this type of damper, the yielding property or the hysterical behaviour of steels during deformation in the plastic region is used, increasing the residual energy and consumption of input energy. These dampers also increase the stiffness of the structural system.

ADAS and Triangular Added Damper and Stiffness (TADAS) dampers are conventional types of yielding dampers in the category of passive structure control systems in terms of system type. In 1978, at Michigan State University, Bergman and Goel conducted the first severe tests for ADAS dampers [5].

The results of other tests on X-shaped steel elements in ADAS dampers showed that these elements have high efficiency in ADAS damper systems and can be used in essential structures geographically located in high seismic risk areas. These elements have stable hysteresis behaviour in the steel-yielding damper during alternating seismic cycles in the inelastic range. This critical feature makes structures equipped with this system different and superior to other structures [6].

In 2013, Farshidianfar and Sohaili [7] first investigated the optimal parameters for mass dampers using the ant colony algorithm to reduce the vibrations of high-rise structures under earthquakes. To reduce the maximum displacement and acceleration of the desired structure floors, they optimized the three parameters of the damper mass, damping and spring stiffness.

Then, in addition to the method of the ant algorithm, with the help of innovative bee colony algorithms and the evolution of the chaotic set, they optimized the design parameters of mass dampers, taking into account the effect of soil and structure interaction in multi-degree-of-freedom structures. Farshidianfar and Sohaili [8] presented good relations of mass dampers for the values of mass ratio, damping and frequency.

In 2016, Mazanoglu and Kandemir Mazanoglu [9] optimized some parameters for viscous dampers between two adjacent buildings. In this paper, they showed that the different seismic properties of the

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neighbouring buildings caused an impact on the structure. It can lead to harmful damage to the structure. These results show that the impact force is dependent on the characteristics of the building. In addition, it was concluded that the supplementary damping ratio for impact prevention is not proportional to the impact forces. This paper optimized and modified the existing design relationships for structures with complementary viscous dampers for two connected buildings. The research showed that the optimal selection of damper properties effectively reduces the displacement response and prevents severe structural shocks.

In their article, Dario et al. [10] investigated the seismic protection by using yield-type dampers in existing structures against rotational oscillation. The structures in the systems of high importance, such as hospitals, fire stations, schools and power plants, often need to comply with the seismic standards that are in force today. Therefore, their design and construction are mainly based on construction guidelines. On the other hand, considering the particular importance of these structures, maintaining the stability and integrated structure of such buildings during and after an earthquake requires a strategy for seismic protection. In this regard, shock absorbers and seismic isolators have been widely used. In this article, the structures were compared in two ways: 1) if it is equipped with a mechanical mechanism in base isolation systems, and 2) one includes a combination of base isolation or yield type dampers.

In 2019, Nabid et al. [11] conducted studies that aimed to improve the computational efficiency and convergence rate by optimizing uniform deformations and to show the reliability of the results obtained from this model compared with other innovative solutions, such as the genetic algorithm. To check the effectiveness of the proposed optimization method, 3, 5, and 10-story frames with friction dampers were optimized using the uniform deformation method, genetic algorithm, and uniform deformation method and genetics. The results show that the uniform deformation method can lead to a solution for optimal design with lower computational costs (up to 300 times less than nonlinear dynamic analysis) compared to genetic algorithms and uniform-genetic deformation methods. Therefore, the uniform deformation optimization method based on this research is reliable for a more effective design of friction dampers [13].

In 2020, Zhang [12] investigated the optimization problem for a yielding steel linear damper in multi-story buildings in his article. In this article, the target structure was modelled by using the internal spring damping system configuration for a multi-story building. The damper used in this study is the ADAS yield type. The stiffness of the damper base has also been taken into consideration, then four types of optimal damper placement arrangements were obtained to reduce the maximum relative displacement of the building according to the size of the moment and the stiffness of the foundation.

In 2022, Khoshkalam et al. [13] examined the types of yielding dampers with different configurations and elements that were made to improve the seismic performance of structures. One of the tools that dissipate the earthquake energy is ADAS dampers. In sever earthquake we can see that the element have a controlled and uniform yielding. This paper proved that under an unexpected tensile axial force the dampers with x-shaped elements could not have an ideal performance in large deformations.

The axial force causes local strain in the middle of the X-shaped plates, and an unexpected increase in the force applied to the damper can damage its principal members. According to the geometry of the proposed damper, the axial force created instead of the triangular plates reaches the braces through the side plates and improves its performance. The results show that in the nonlinear range the power level increase for the Modified Added Damping and Stiffness (MADAS) damper is about 30%, while it exceeds 150% for the conventional ADAS dampers. On the other hand, the equivalent maximum plastic strain in ADAS is twice that of MADAS. In addition, the evaluation of uniform, cyclic and dynamic behaviours shows that the MADAS dampers introduced in this research show a lot of energy loss in large deformations [14].

2 | Metodology of Research

The plan of the selected structures is chosen due to considering the torsional effects in the asymmetric structure. Therefore, by modelling a 15-story steel structure with steel braces in at least four retrofitting models with ADAS dampers (in different spans, in other words, four different types of damper arrangements), the seismic behaviour of each is addressed. The selection criterion of these structures is the investigation of high-order structures and the investigation of finding the optimal models of retrofitting with optimized dampers based on neural networks [15]. In this regard, nonlinear dynamic analysis of Incremental Dynamic Analysis (IDA) uses at least ten accelerations of the area near the fault so that the minimum distance from the earthquake's epicentre is less than 15 km, for which the acceleration introduced in FEMA-P695 regulations is used. Therefore, in this regard, Etabs software is used for the initial design of structures and OpenSees software is used for nonlinear analysis.

2.1 | Metodology of Research

In this research, multilayer neural networks with error backpropagation algorithms have been used to estimate the optimal design values of ADAS dampers exposed to successive critical earthquakes. A backpropagation network is a multilayer network with a nonlinear transfer function and the Widrow-Hoff learning rule. In this network, the input and target vectors are trained to approximate a function, find the relationship between input and output, and categorize neural network inputs. With Bias, one or more sigmoid intermediate layers and a linear output layer, this network can estimate any function with a limited number of discontinuity points. The standard back propagation network is a slope-reducing algorithm in which the network weights move in the direction opposite to the slope of the efficiency function. In this algorithm, it is first assumed that the network weights are chosen randomly, and the network's output is calculated in each step. Then, the consequences are corrected according to the amount of difference between the output and the target, minimizing the error. In the backpropagation algorithm, the excitation function of each nerve is equal to the weighted sum.

The related entries are considered. In the next step Levenberg-Marquardt method is used to communicate the error with inputs, weights and outputs. This standard method for most minor squares problems combines the Newton-Goss approach and maximum descent [11], [12], [15]. This algorithm randomly divides the data into three parts: training, validation and testing. *Fig. 1* shows the view of the networks used in this research.

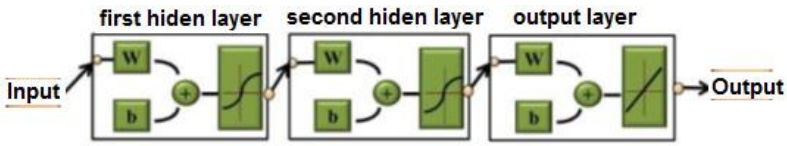

Fig. 1. A view of the networks used in this research.

In the current research, 60% of the data is used for training, 35% for testing to prevent network overfitting, and 5% for validating the neural network. The stop criterion for network training is the Mean Squared Error (MSE). In such a way that low MSE values mean better network performance, and zero value means no mistakes. On the other hand, the regression values (R) represent the degree of correlation between the outputs of the network and the target. In this way, R = 1.0 means complete correlation, and R = 0 indicates randomness and lack of correlation; therefore, two criteria, MSE and R, are chosen to select the ideal neural network. To obtain a suitable neural network model, it is indispensable to use homogeneous information. In this regard, among the characteristics of the earthquake, parameters such as PGA, EPA, the magnitude of the first and second earthquake and the characteristics of the structure such as the type of structure, height, etc., in the form of the periodic time parameter (T) as input and the reduction behaviour coefficient. The result of the consecutive occurrence of earthquakes in the seismic scenarios used in the results of the analysis of the selected frames of this research have been selected as the target values for training, testing and verifying the accuracy of artificial

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neural networks. The interval time parameter separates the results of the frames from each other. Also, to avoid the problem of overfitting, the appropriate number of nodes is selected in the hidden layer. Because this number of nodes strongly affects the performance of the neural network. In such a way, a very small number leads to the inability of the network to fit the data, and a very large number will cause the phenomenon of overfitting the data with a high degree curve and high fluctuations.

As mentioned earlier, the sigmoid transfer function is used in hidden layers in neural networks. This function always behaves between zero and one. In this way, before training networks, it is necessary to normalize all data, including input and target values. In this regard, the linear interpolation method has been used to scale the data. After introducing the formalized input and target data to the network and training until the error rate is minimized, the desired output is extracted.

3 | Introduction of Material Specifications

The investigated structure is steel. In modelling the linear behaviour of the structures, the properties of the lower edge of the material resistance are used. On the other hand, in modelling the nonlinear behaviour of structures controlled by deformation, the expected resistance characteristics of materials are used, which is based on FEMA-356 and the instructions for improving the characteristics of materials scheduled as follows in *Eq. (1)* to *Eq. (4)* and *Table 1*. Due to *Eq. (1)* to *Eq. (4)*, Fy is the yield stress, Fu is the ultimate stress, Fye is the elastic yield stress, and Fue is the ultimate elastic stress of dampers used in this research [13], [16].

$$F_y = 2400\frac{kg}{cm^2}. \tag{1}$$

$$F_u = 3700\frac{kg}{cm^2}. \tag{2}$$

$$F_{ye} = 1.1 * \ 2400) = 2640\frac{kg}{cm^2}. \tag{3}$$

$$F_{ue} = 1.1 * \ 3700) = 4070\frac{kg}{cm^2}. \tag{4}$$

Table 1. Dedicated sections for structures modeled in Etabs.

STORY	Column Section	Brace Sections	Beam Section
First to fifth floor	Box 500*500*20	Tubo 140*140*14.2	IPE 360
6th to 10th floor	Box 400*400*15	Tubo 140*140*14.2	IPE 360
10th to 15th floor	Box 350*350*15	Tubo 140*140*14.2	IPE 330

4 | Desining the Structure with a Damper

Usually, the damping of typical structures is about 5%, and we draw the design spectrum according to this amount of inherent damping in the structure. But when a damper is used in the structure, the values of the maximum acceleration of the spectrum decrease. At the beginning of the design, there is no information about the operated damper. Therefore, to model a linear damper in Sap software, it is necessary to enter the damper characteristics, such as effective stiffness and damping. Therefore, use nonlinear dampers less than possible because conventional design software such as Sap usually converges with difficulty. Therefore, linear dampers have been used for this structure. For the damper to work linearly, its stiffness should be high but not so high that convergence does not occur. It is recommended that this value $\lambda =$ (CD/KD) be one order more minor than the loading time step value Δ_t. For example, the hardness value can be considered as follows [14], [17], [18]:

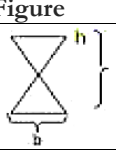
$$K_D = \frac{1000C_D}{\Delta_t}. \tag{5}$$

Due to *Eq. (5)*, where the CD coefficient is the damping coefficient of the used damper. According to the regulations of NEHRP and ASCE7-10, the value of the overall damping coefficient of the structure is calculated from the relationship in the following relation number 6:

$$\beta_m = \beta_1 + \beta_{vm}\sqrt{\mu} + \beta_M . \tag{6}$$

The β_m is the effective damping ratio in the m-th mode of vibration, and β_I is inherent damping due to pre-yielding energy dissipation of the structure (β_I = 5% or less unless higher values can be justified). $\beta\_vm\ \sqrt{\mu}$ equivalent viscous damping of EDS in the m-th mode. β_H Is hysteretic damping due to post-yielding behaviour in structure. All dampers used in the structure must be by the regulations. in this research, ADAS dampers have been used with the specifications in *Table 2*, where each damper consists of several parts X (for ADAS damper). The behaviour of the dampers is considered bilinear hardening. The placement of dampers in the building frame is considered as four models, shown in *Figs. 2-5*.

Table 2. Characteristics of metal dampers (ADAS, TADAS) used in the models.

Figure	b (Cm)	h (Cm)	t (Cm)	Δy(cm)
	20	30	1.5	0.24

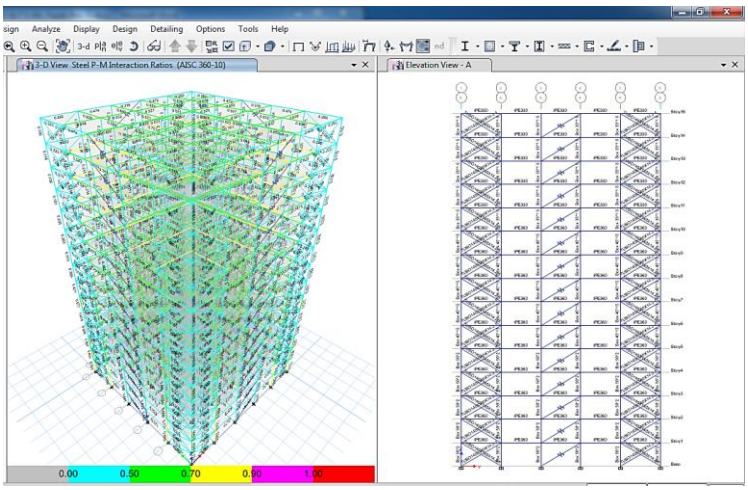


Fig. 2. Placement of the first model of dampers in structures (type 1).

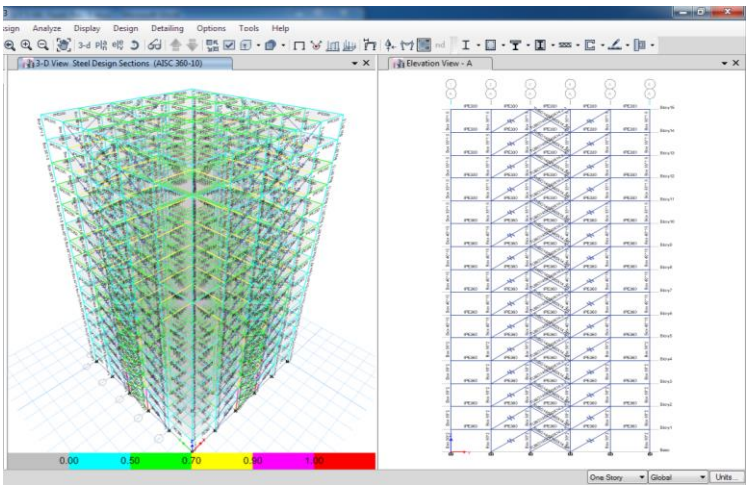


Fig. 3. Placement of the second model of dampers in structures (type 2).

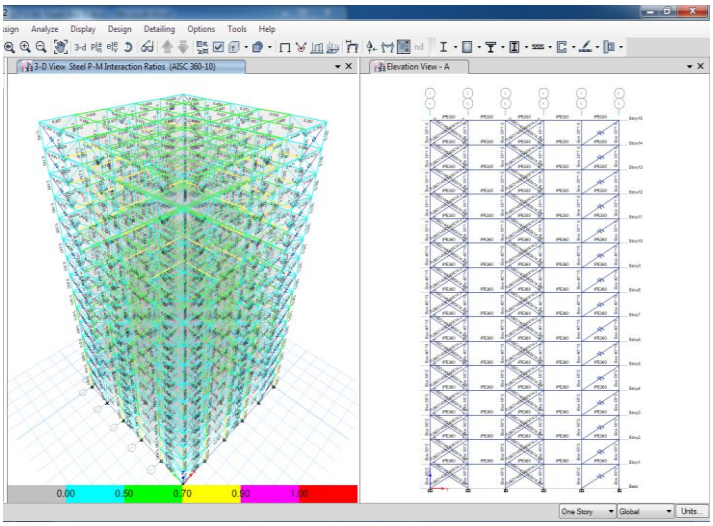


Fig. 4. Placement of the third model of dampers in structures (type 3).

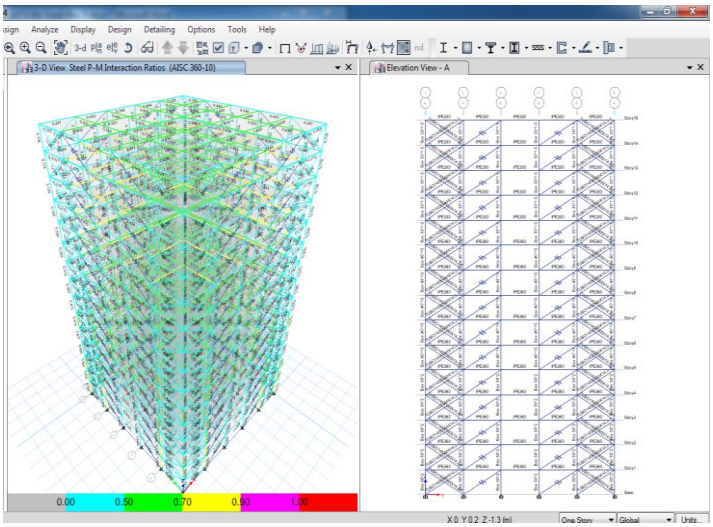


Fig. 5. Placement of the fourth model of dampers in structures (type 4).

After analysis in SAP software, structure models in OpenSees Software. It should be noted that in order to reduce the amount of analysis operations in IDA in OpenSees software, which sometimes lasts for several days, we use 2D frame modeling of the structure, which subjected in more critical conditions. For this purpose, we will need to select a number of acceleration in near field area.

5 | Definition in Incremental Dynamic Analysis

The ground Intensity Measure (IM), is a scaled quantity of a scaled acceleration. The DM quantity is also a positive numerical value that expresses the characteristics of the response of the structural model against the desired seismic loads, or in other words, it determines the excess response of the structural model due to seismic loading.

$$DM \in [0, +\infty). \tag{7}$$

To summarize the IDA curve, the numerical values of the performance levels can be summarized into a few intermediate numbers along with the dispersion index (standard deviation or difference between two values). Therefore, we calculate the values of 16%, 50% and 84% as the numerical values of damage for the corresponding IMs for intensity at each performance level.

6 | Selection of Acceleration

The first step in the functional evaluation process of IDA curves is to prepare sets of earthquake acceleration, so that this set represents the seismicity of the desired area. In this research, in order to reduce the error caused by the selection of acceleration, the number of 10 acceleration due to FEMA-P695 has been used, and the assumptions for the selection of these acceleration are given in the introduced reference.

7 | Result Discussion

7.1 | Result of Incremental Dynamic Analysis

The selected frames of the analyzed structures were modelled in the two-dimensional form in the OpenSees software, and the general outline of the modelled frames is shown. In addition, the results of IDA analysis have been obtained, and the comparison of their 50% averages for all three frames is shown in the figures. In this regard, the neural network technique has been used using MATLAB and OpenSees software.

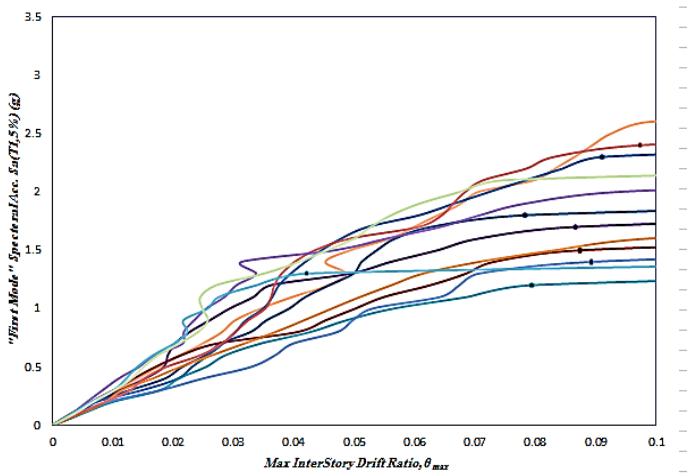


Fig. 6. IDA curves obtained for a 15-story structural frame (type 1).

Fig. 6 shows IDA curves obtained for a 15-story structural frame on a type of first-modelled building are given. Also, in *Fig. 7*, IDA curves are summarized as 16%, 50% and 84%.

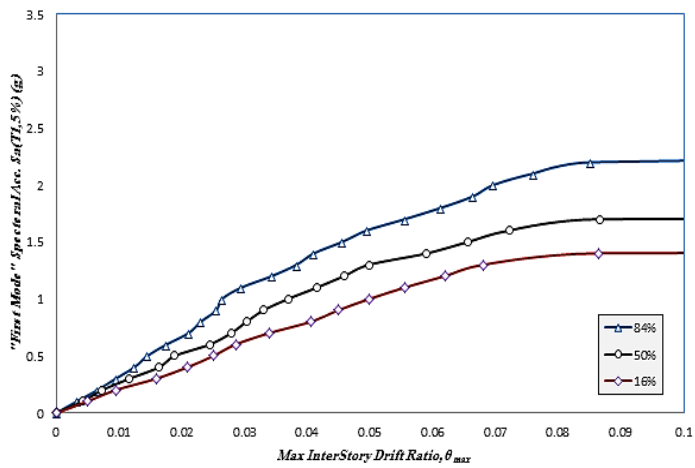


Fig. 7. 16%, 50% and 84% curves for IDA curves obtained for 15-story structural frame (type 1).

Fig. 8 shows IDA curves obtained for a 15-story structural frame on a type of second-modelled building are given. Also, in *Fig. 9*, IDA curves are summarized as 16%, 50% and 84%.

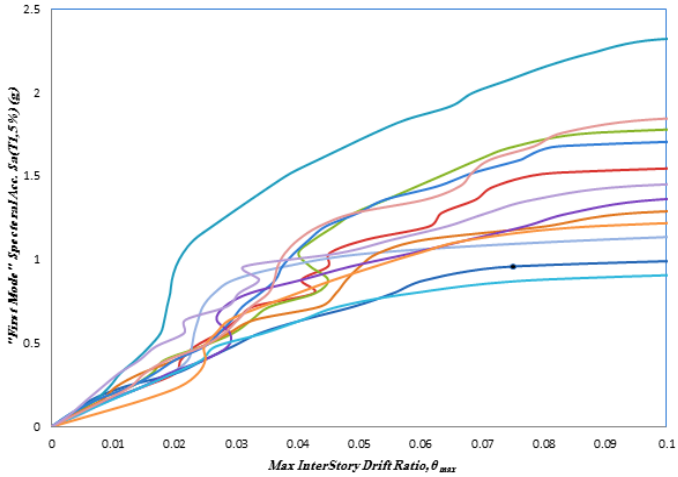


Fig. 8. IDA curves obtained for a 15-story structural frame (type 2).

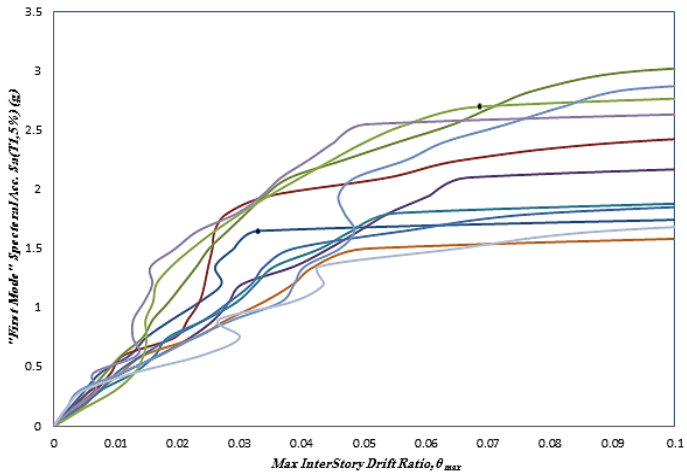


Fig. 9. 16%, 50% and 84% curves for IDA curves obtained for 15-story structural frame (type 2).

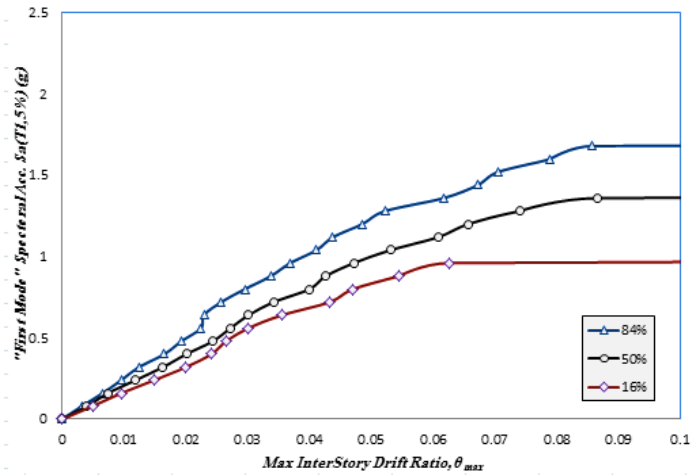


Fig. 10. IDA curves obtained for a 15-story structural frame (type 3).

Fig. 10 shows IDA curves obtained for a 15-story structural frame on a type of third-modelled building. Also, in *Fig. 11*, IDA curves are summarized as 16%, 50% and 84%.

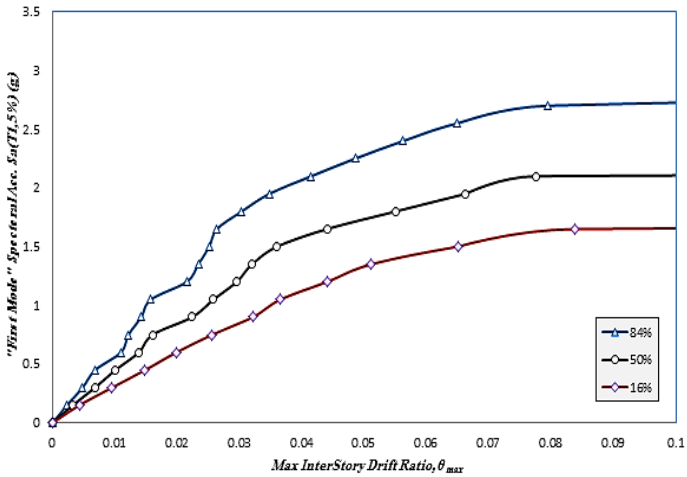


Fig. 11. 16%, 50% and 84% curves for IDA curves obtained for 15-story structural frame (type 3).

Fig. 12 shows IDA curves obtained for a 15-story structural frame on a type of forth-modelled building. Also, in *Fig.13*, IDA curves are summarized as 16%, 50% and 84%.

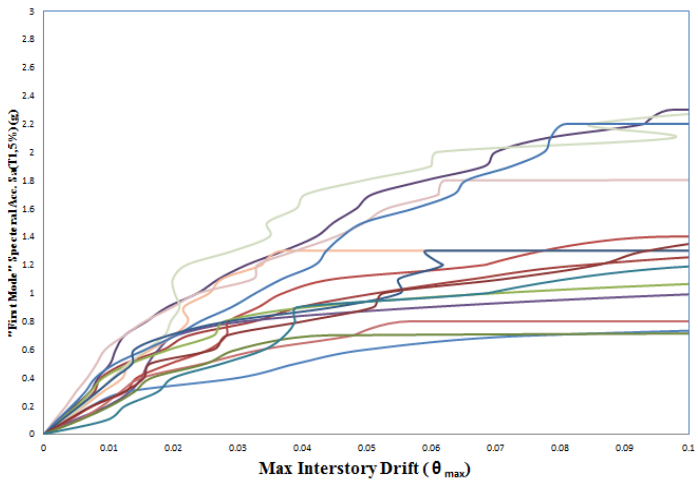


Fig. 12. IDA curves obtained for a 15-story structural frame (type 4).

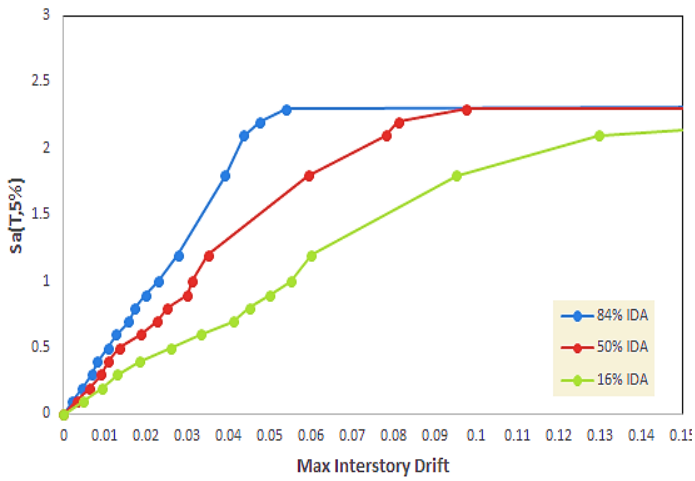


Fig. 13. 16%, 50% and 84% curves for IDA curves obtained for 15-story structural frame (type 4).

Fig. 14 compares 50% IDA analysis curves for all four structural frames. As can be seen, the structure of the third type has more rigidity. At a higher level of seismic intensity, the corresponding curve

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becomes horizontal, and the second type's structure has more plasticity and becomes horizontal at a lower level of seismic intensity.

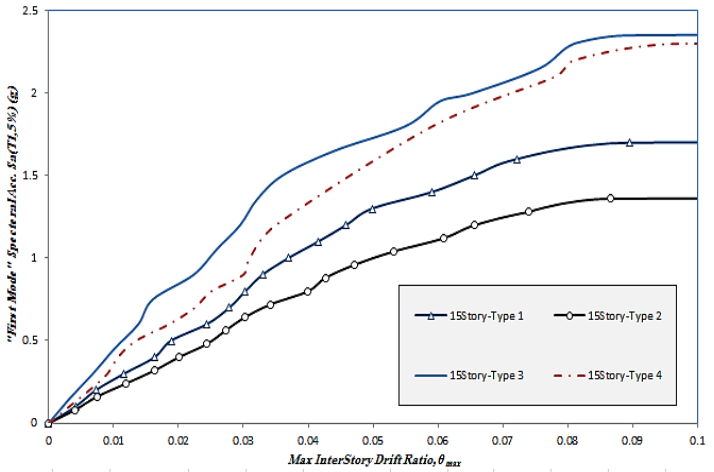

Fig. 14. Comparison of 50% curves of IDA analysis curves for all 4 structural frames.

7.2 | Access to Fragility Curves

As mentioned in this paper, graphs called fragility curves are used to extract the probability of occurrence of limit states from the outputs of IDA analysis. For all the acceleration, the mappings are arranged in descending order. It should be noted that according to FEMA 350 guidelines, the limit state of destruction (CP) is the point equivalent to 20% of the initial average slope, which corresponds to the starting point of the horizontalization of the IDA curves. Fragility curves are obtained, and their comparison is drawn in the following figures.

Fig. 15 shows the fragility curves obtained from IDA curves for the failure level corresponding to the 15-story structural frame of the first type of building for two failure levels of immediate occupancy and collapse prevention.

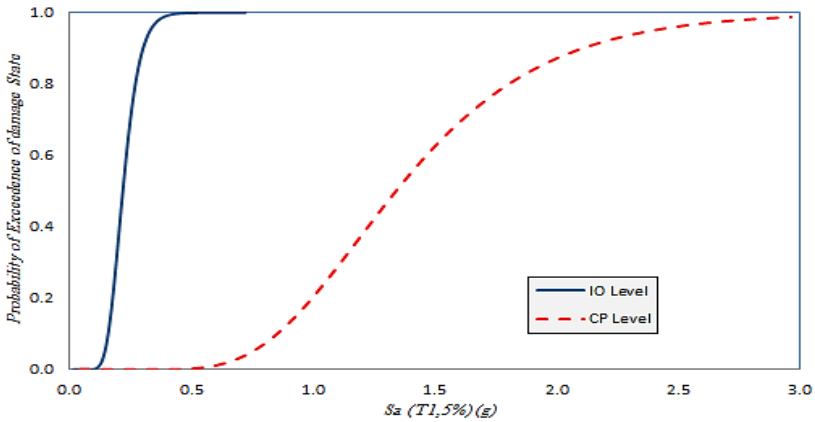

Fig. 15. Fragility curves resulting from IDA curves for the failure level corresponding to the 15-story structural frame (type 1) for the IO and CP failure levels.

Fig.16 shows the fragility curves obtained from IDA curves for the failure level corresponding to the 15-story structural frame of the second type building for two failure levels of immediate occupancy and collapse prevention.

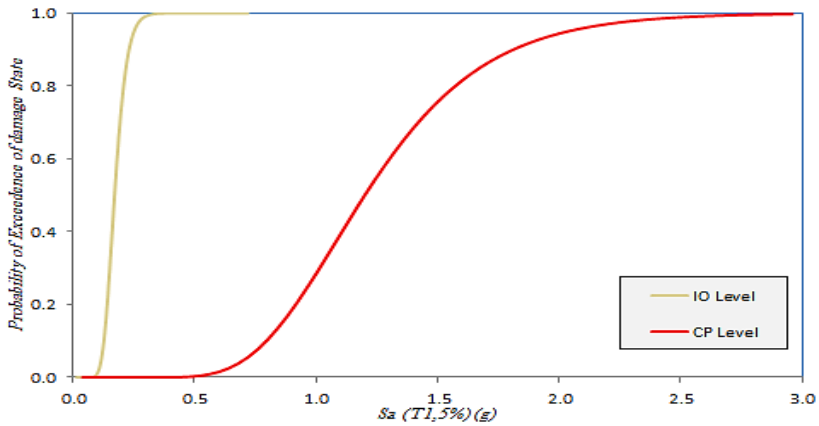

Fig. 16. Fragility curves resulting from IDA curves for the failure level corresponding to the 15-story structural frame (type 2) for the IO and CP failure levels.

Fig. 17 shows the fragility curves obtained from IDA curves for the failure level corresponding to the 15-story structural frame of the third type building for two failure levels of immediate occupancy and collapse prevention.

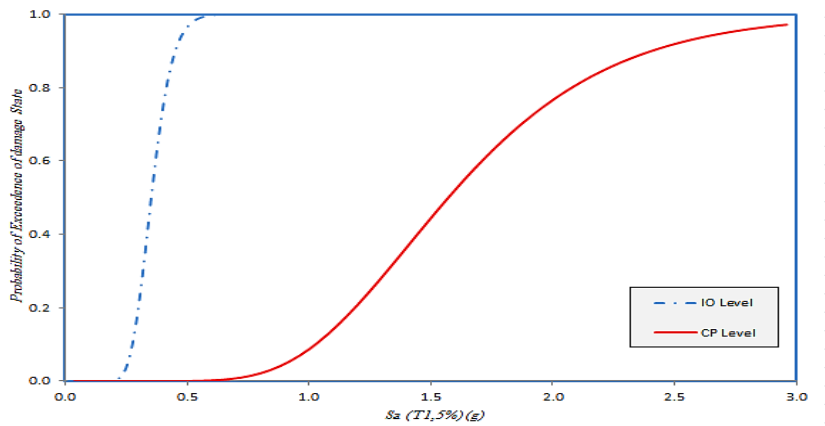

Fig.17. Fragility curves resulting from IDA curves for the failure level corresponding to the 15-story structural frame (type 3) for the IO and CP failure levels.

Fig. 18 shows the fragility curves obtained from IDA curves for the failure level corresponding to the 15-story structural frame of the fourth type building for two failure levels of immediate occupancy and collapse prevention.

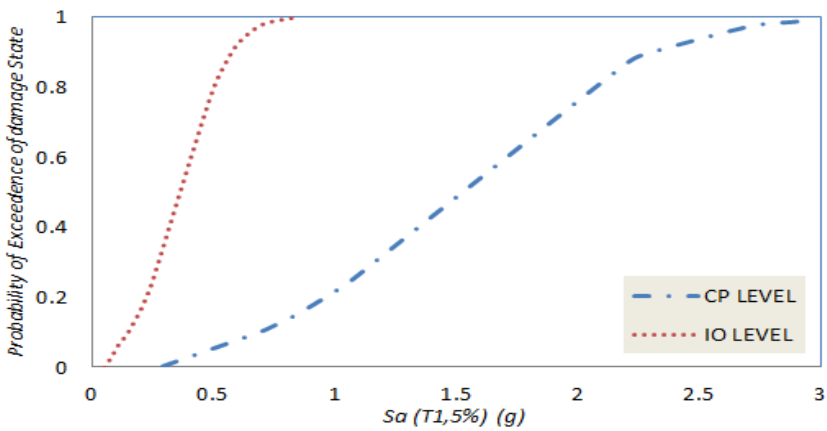

Fig. 18. Fragility curves resulting from IDA curves for the failure level corresponding to the 15-story structural frame (type 4) for the IO and CP failure levels.

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Fig. 19 compares the fragility curves obtained from the IDA curves for the failure level corresponding to the continuous use failure level and the collapse threshold for all four structural frames. As can be seen, a noticeable trend in each of the four structures is not observed in the other.

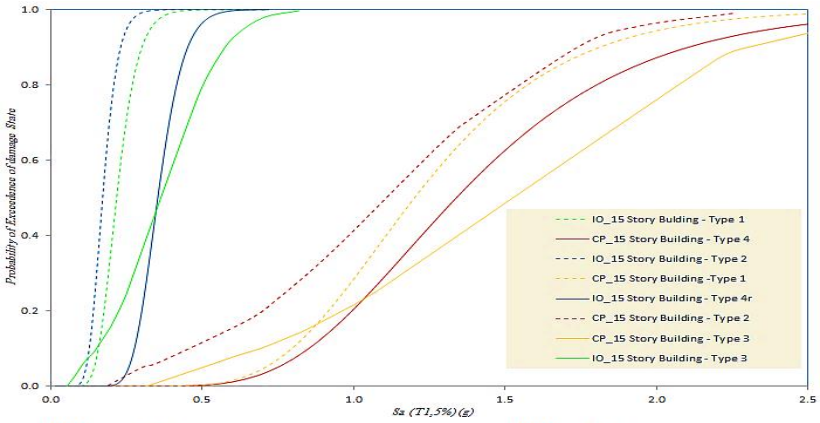

Fig.19. Comparison of fragility curves resulting from IDA curves for CP and IO failure levels for all four structural frames.

8 | Conclusion

This research investigated the behaviour of structures with optimal ADAS dampers in four placements. Although this kind of work has been done less comprehensively in the country and the growing trend of using this retrofitting of existing structures, such a project can be a new and marketable step in this direction. Therefore, results such as the following could be extracted from this research:

I. As seen in different locations of dampers, different behaviour is observed in the structures. Also, the type of damper due to the different hardness and performance led to the change in the behaviour of the structures modelled in this research. It can be concluded that the performance of all four types of damper arrangement is very close to each other, and the nonlinear analysis error in this software can cause the existing difference. Also, according to the results and considering the structure in terms of architecture, all four types of arrangement have good performance and energy absorption against earthquakes.
II. The use of dampers in types 3 and 4, by increasing the stiffness of the structure, leads to a decrease in the relative displacements of the floors, thereby reducing structural and non-structural damages, and it shows that this type can be led to more energy absorption.
III. TADAS and ADAS dampers have good seismic behaviour and can withstand many cycles without losing hardness and resistance.
IV. Using dampers sample structures under the earthquake energy records a positive effect on the reinforcement of the structures and the appropriate behaviour of structural and non-structural members against damage and destruction. By using this technology, we can hope that the amount of damage will reach its lowest level and that the lives of thousands of people will be saved after severe earthquakes.

Author Contributions

Author 1 planned the scheme, initiated the project, and suggested the simulation. Author 2 conducted the numerical simulation and analyzed the results. Author 3 developed the simulation result and modeling and examined the theory validation. The manuscript was written through the contribution of all authors. All authors discussed the results, reviewed, and approved the final version of the manuscript.

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Data Availability Statement

"Not applicable".

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Conflicts of Interest

This is the original work of the authors and all authors have seen and approved the final version of the manuscript being submitted. The material described here is not under publication or consideration for publication elsewhere. "The authors declare no conflict of interest".

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