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Investigation and comparison of two new dampers in short, medium and long structures

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Abstract

An earthquake is one of the most common natural phenomena, which causes a lot of human and financial losses due to the impossibility of predicting and preventing it. Iran is one of the regions with high earthquake risk in the world due to special tectonic conditions and the existence of active faults and high seismicity. New methods in earthquake engineering, especially in recent decades, have had a significant impact on reducing seismic damage to structures. Over the years, researchers have introduced a variety of methods to reduce earthquake damage to structures. However, the existence of economic issues arising from the use of innovative equipment has always been the subject of public debate. Structural control is one of the effective methods of earthquake engineering to reduce seismic response. Structural control means that the characteristics of the dynamic behavior of the structure are adjusted in such a way that the response of the structure does not exceed the allowable limits due to external stimuli. One way to control the structural behavior is to use dampers. In this research, the performance of a multi-level pipe in pipe damper and a new brace-type slit damper in structures is investigated. In this paper, first, four structural models including two 5 and 10 story models with the same plan and two 10 and 15 story models with the same plan are modeled in SAP software. Then the same structure is examined by considering the pipe damper in the pipe. The results show that the presence of this type of damper reduces the structural responses, including drift and displacement of the maximum roof to an acceptable extent. Also, according to the models, the performance of brace-type slit damper was better than multi-level pipe in pipe damper.

"Keywords: Damper ; Earthquake ; Seismic Resonse ; Structural"

1. Introduction

An earthquake is one of the major natural disasters of the present age, which has always caused great catastrophes in a very short period of time. Stability and safety against natural phenomena have always occupied the human mind. Earthquakes have always existed as a recurring phenomenon throughout history and will continue to exist in the future. Iran is one of the regions with high earthquake risk in the world with special tectonic conditions and the presence of active faults and high seismicity. Certificate of history, scientifically based information, and experience of frequent earthquakes,

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especially in recent years, indicate that most parts of the country are prone to severe earthquakes, which are vulnerable and endangered due to development incompatible with earthquake risk. In recent decades, many control systems have been studied to reduce the vibrations of structures due to dynamic forces. These systems are generally divided into four main categories: passive, semi-active, active, and mixed control systems. The passive control system is a system that increases energy dissipation or changes in the frequency of the structure, without the need for an external energy source. Structural control is one of the effective methods of earthquake engineering to reduce seismic response. Structural control means that the characteristics of the dynamic behavior of the structure are adjusted in such a way that the response of the structure does not deviate from the allowable range due to external stimuli. One of the tools to control the behavior of the structure is dampers or vibration absorbers. In this research, we try to provide a proposed arrangement to improve the performance of dampers, by increasing the range of motion of these dampers, increase the amount of energy absorbed by the dampers and thus reduce the damage caused by earthquakes. In other words, more energy can be absorbed with less displacement in the frame. The concept of passive control is to add energy dissipation devices to the structure. In fact, devices that do not require external energy to operate are called passive control devices. These systems are more reliable because they continue to operate when the power supply is cut off during an earthquake. These devices have a low maintenance cost. Of course, most passive control devices were used after stages such as friction slip, metal yield, deformation in objects or viscoelastic liquids, and therefore they can be designed to be used after a certain level and for low lateral forces They did not work. The use of passive control devices is effective both in the improvement of structures and in the initial design of structural systems. For example, the structure needs an additional stiffness to absorb the dynamic response of the structure and reduce the vibration energy by changing the initial frequency and help prevent resonance. Thus, these devices can replace such additional rigidity.

Steel yielding dampers and friction dampers are two systems effective in energy dissipation. The idea of using steel energy dissipates in structures to absorb the seismic energy of conceptual and experimental work[1] and Skinner[2] began. They introduced and tested various simple steel devices as energy dissipation tools. U-shaped metal strips were among these tools. The results of reversible load tests showed that U-shaped metal strips can operate with large displacements in the inelastic range and waste energy through the plastic deformation of steel. Another type of these devices is the added rigidity and damping elements (ADAS), which are designed to dissipate seismic energy by deforming the bending yield of soft steel plates[3]. After a few years, the energy absorption and dissipation properties of steel U-shaped elements were studied and confirmed by another group of researchers in a series of experiments in 1992[4]. Additional studies on this damper were performed by Dulles[5]. They experimentally and numerically tested the circular arrangement of U-shaped strips as an elastoplastic pixel device for passive control of structures. The use of two- or multi-level control systems is one of the new methods that has attracted the attention of researchers in recent years. The main idea of these systems is to combine different control systems with different hardness and resistances, which results in the dissipation of optimal energy at different levels of the earthquake. Balendra et al[6] proposed a two-level passive control system consisting of a knee brace and a connection to the perforated body. At low service loads and forces, the grooved joint creates energy dissipation through friction damping, while in severe earthquakes, energy dissipation is provided by the elastic behavior of the knee joint. Zahraei and vosuogh[7] conducted a study on the dual system, using a combination of vertical connection beam and knee elements. At low forces, the plastic joint on the vertical joint increase's energy dissipation, and the plastic deformation of the knee increases the ductility and energy absorption under strong forces, thus improving the seismic performance[8].

2. Introducing the dampers used in the research

The main idea of the damper used is schematically shown in Fig. 1[7]. As can be seen, the damper consists of a number of nested tubes connected by pistons. There is an empty space between each pipe and the next pipe, which is due to the flexural strength and stiffness of the outer pipes, which can be calculated according to their diameter and thickness. By applying this lateral force to the brace, the outer tube begins to deform and the occurrence of localized plastic strains causes energy dissipation. By increasing the force as a result of increasing the distortion of the outer tube wall, its connection to the inner tube increases the stiffness and strength of the system and the participation of both tubes in energy dissipation.

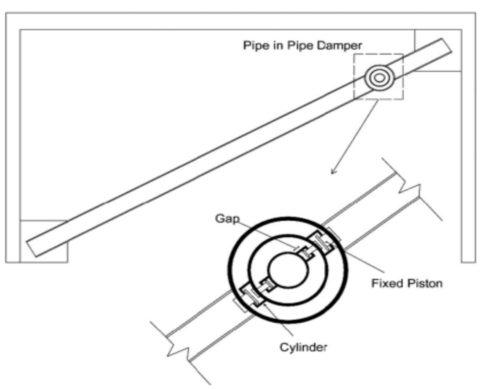

Fig. 1. The main idea of the damper used in this research[9]

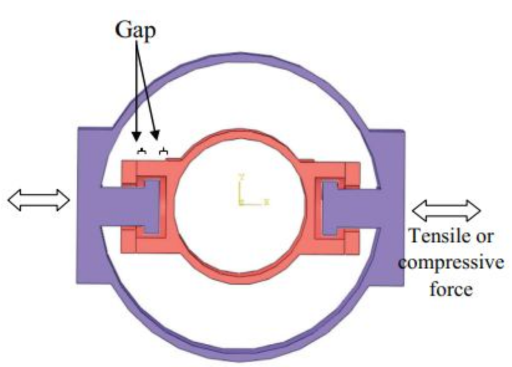

Fig. 2- Damping section, showing the proposed mechanism[9]

In order to show the proposed damping mechanism, the cross-section is shown in Fig. 2. Initially, the sections of the two pipes are completely independent and only the flexural strength of the outer pipe resists the applied forces. Then, with increasing force and displacement, the inner and outer tubes engage with each other and increase stiffness and strength due to the combined performance.

Another damper used is a new diagonal brace-type slit damper consisting of several steel parts[10]. Fig. 3 shows the configuration of this damper in a simple steel frame. As seen, this damper consists of a series of damper links (a slit plate) connected to two side elements. Each element should be constrained at its two ends using different details. A pinned connection must be utilized on one end and at the other end, only the out-of-plane displacement should be restrained by a gusset plate. These details provide such boundary conditions for BSD that under the lateral deformation of the frame, the damper would deform as shown in Fig. 4.

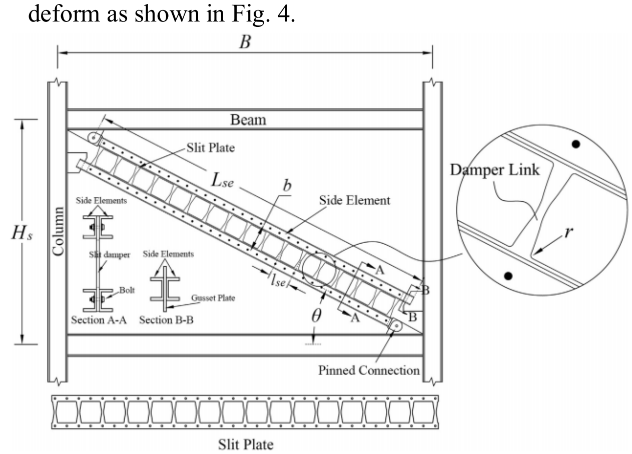

Fig. 3. Configuration of BSD in a steel frame[10]

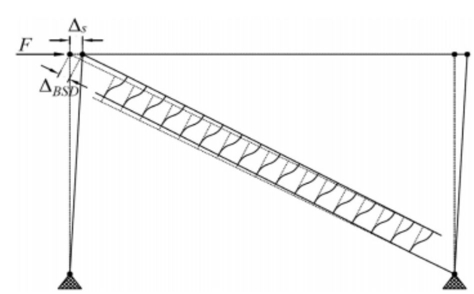

Fig. 4. Lateral deformation of a frame equipped with BSD[10]

3. **Investigating the effect of dampers in improving the seismic response of moment frames**

In this section, the effect of the proposed damper on improving the seismic performance of structures is evaluated. For this purpose, 4 buildings of 5, 10, and 15 floors with the plan shown in Fig. 5 are designed as representatives of short, medium, and tall buildings in accordance with the criteria of Iranian 2800 standard [11], respectively, and then a frame of each the plant are used for additional dynamic analysis. It placed. The height of all floors was considered to be 3.2 meters, Dead and live loading of 500 and 200 kg/m2, respectively.

The structure is designed with a Sway intermediate lateral bearing frame with the assumption of residential use and location in a relatively high-risk area located on type 1 soil. The used steel of ST37 type with a yield stress of 2400 kg/cm^2, modulus of elasticity of 2×10^6 kg/cm^2 and Poisson's ratio of 0.3 was selected. IPE sections were also used to model the beams and IPB sections were used for the columns. The cross-sections of the beams and columns can be seen in Fig. 6 and the plan shows in Fig. 7.

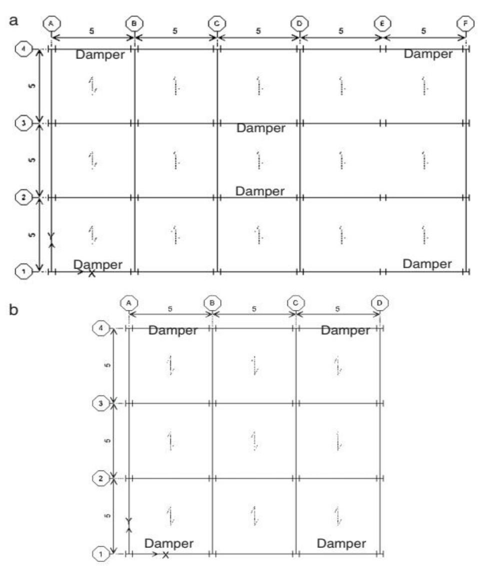

Fig. 5. Floor plan

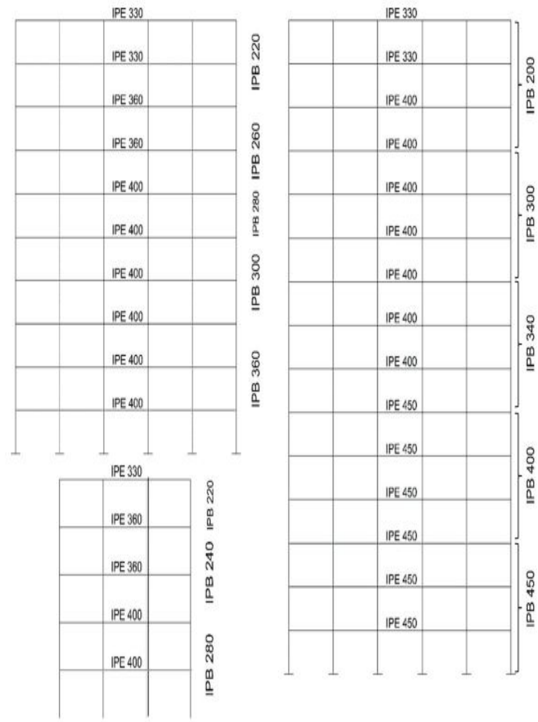

Fig. 6- Beam and column sections

3.1. Selected earthquake records

To evaluate the performance of the proposed damper during seismic loading, 3 acceleration maps with maximum acceleration, duration, and different frequency content was used according to Table 1. According to standard 2800, accelerometers are first scaled to their maximum value so that the maximum acceleration of all of them is equal to g. Then the combined response spectra in the time range of 0.2 to 1.55 times the periodicity of the structure are compared with the standard design spectrum. Finally, the scale coefficient should be chosen so that in the mentioned range, the values of the answers are not less than 1.4 times the values of the standard design spectrum. Then, by multiplying the mentioned scale coefficient in accelerometers, they can be used in dynamic analysis

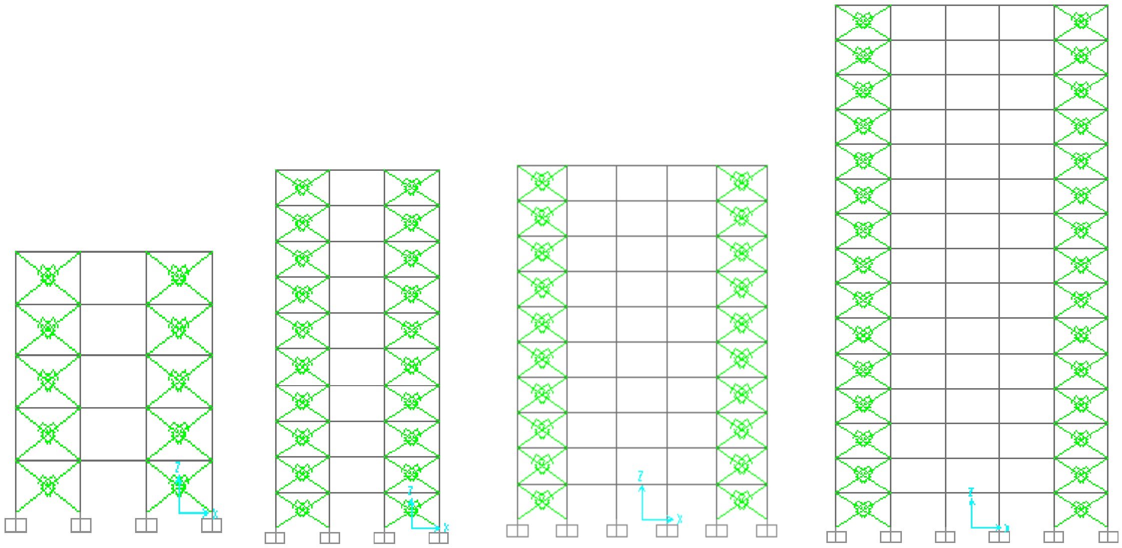

Fig. 7. View of the plans

Table 1. Specifications of selected records

Event Name	Year	Station Name	Magnitude	pga	Significant duration
Imperial Valley-06	1979	Calexico Fire Station	6.53	0.205	15
Kobe, Japan	1995	Kakogawa	6.9	0.339	13
Manjil, Iran	1990	Abhar	7.37	0.22	21

3.2. Validation and modeling with software

In this section, using SAP software and performing nonlinear analysis of the 3D model, the proposed model is reviewed. Because in most of the valid standards of the world, the loading pattern is used to increase the displacement to evaluate the behavior of structures, in this part of the research for nonlinear static analysis of the increasing displacement pattern in the direction of the X-axis and in time steps of 0.1 seconds Due to the effect of large deformations, it was used to buckle the members. Also, because the pipes in the market are usually made of higher carbon steel than mild steel, the steel used is CT20, and its stress-strain curve is a three-line and according to Fig. 8.

Because it is difficult to accurately model the nonlinear behavior of elements in computer programs, it is common to try to use a two- or multi-linear model. For this purpose, according to the models reviewed by Zahraei [12], a model with a diameter of 610 mm outer tubes with a thickness of 30 mm and a diameter of 324 mm inner tube with a thickness of 15 mm was selected for validation.

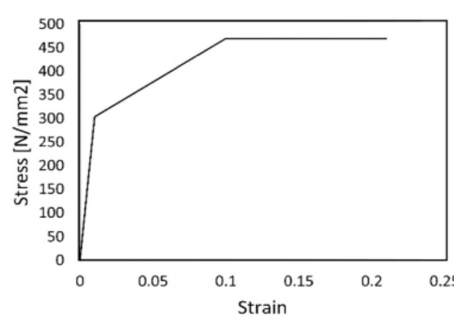

Fig. 8- Characteristics of steel used

It should be noted that in order to introduce the proposed dissipate behavior to SAP2000 software and for ease of operation, its three-line performance

Table 3. Impact of dampers during the period of the structure

	frame	A plan – 15 story		A plan – 10 story		B plan – 10 story		B plan – 5 story	
	Period (seconds)	Bare frame	Frame with damper	Bare frame	Frame with damper	Bare frame	Frame with damper	Bare frame	Frame with damper
Direction Y	Mode 1	2.62	2.62	1.88	1.88	1.8	1.88	1.88	1.88
Torsion mode	Mode 2	1.94	1.92	1.46	1.43	1.31	1.25	0.8	0.69
Direction X	Mode 3	1.66	1.07	1.27	1.22	1.25	1.21	0.76	0.68

The curve is extracted according to the hysteresis curve of laboratory samples. In order to check the accuracy of the results and ensure the matching of specifications and parameters used in the software with real conditions and validated models in the article [9], a frame with the specifications of Table 2 was modeled in the software and loading conditions were applied according to the mentioned cases.

Table 2. Specifications of the validation frame

Type	Section
Beam	IPE 200
Column	BOX150 × 150 × 10
Brace	2UNP200
Height [m]	3.2
Length [m]	6

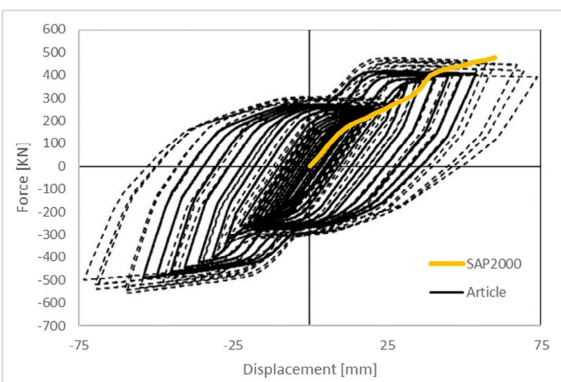

Fig. 9 - Matching numerical results with a reference article

As can be seen, the force changes in the cyclical shifts and load cycles have a noticeable correlation. The sample was stopped in numerical analysis at a displacement of 5 mm due to large deformations and lack of convergence of the results, while the loading of this sample in the laboratory continues until displacement of about 75 mm [12], Fig. 9 shows the appropriate agreement of the software results with the article (numerical and laboratory sample).

4- Analysis results

The period of the structure is one of the most important parameters in its behavior during dynamic loading. Therefore, in order to investigate the effect of the damper in changing the dynamic characteristics of the structure, it is first examined. As can be seen in Table 3, the results show a significant effect of the damper in reducing the period of the structure and the amount of impact will be affected by the technical characteristics of the damper and the number and arrangement of the structure.

It should be noted that the change in the period of the structure as an effective parameter in the amount of force applied to it during seismic loading according to the standard design spectra should always be considered in the design and improvement of the structure. The results of the analysis indicate the tangible effect of the proposed damper in reducing the behavioral parameters of the structure such as maximum displacement, reduction of roof displacement, and period.

According to Fig.s 10 to 13, the maximum displacement of the roof in a 5-story frame equipped with a damper compared to the bending frame only has a ratio between 0.2 to 0.5, and this value was 0.3-0.5 and 0.6-0.8 in 10 and 15-story frames, respectively. According to this, we have also seen a decrease in roof drift. But on the other hand, the use

Of a new damper (BSD) has reduced the roof displacement in the X direction by more than 50%.

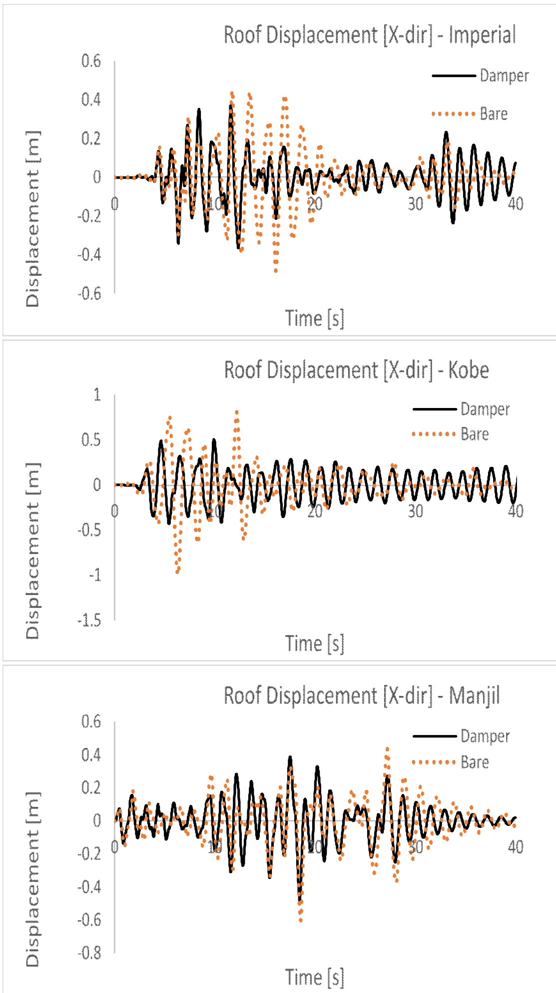

Fig. 10. Roof Displacement the 15-story structure - Plan A.

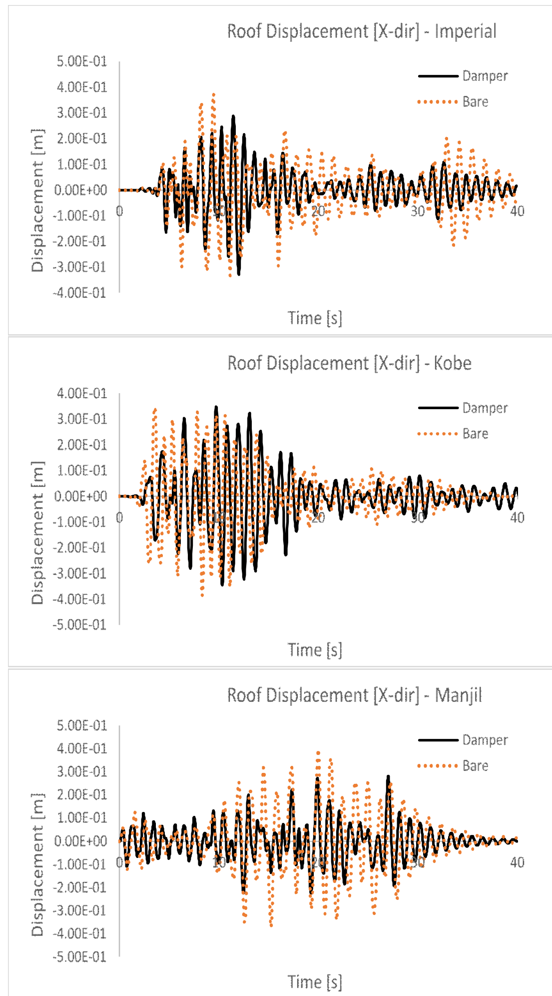

Fig. 11. Roof Displacement in the 10-story structure - Plan A.

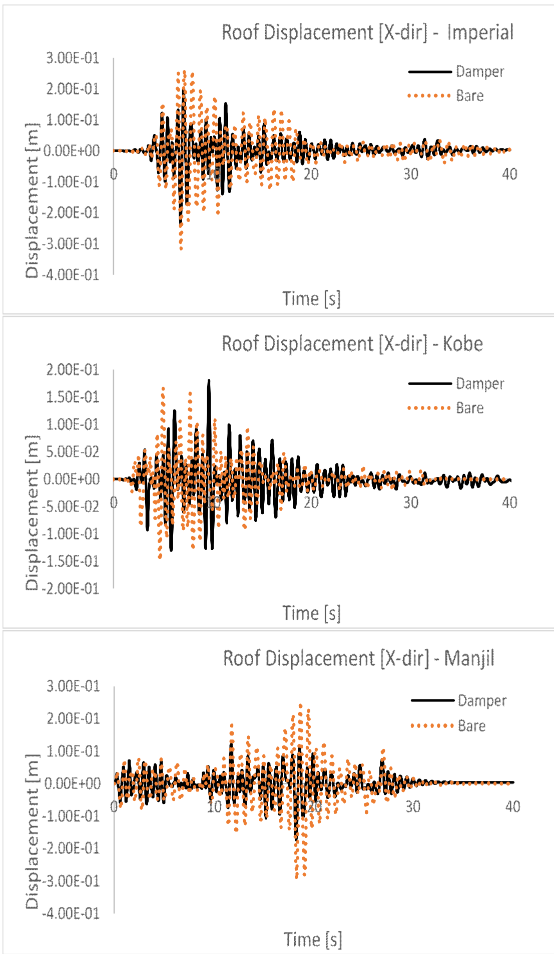

Fig. 12. Roof Displacement in the 5-story structure - Plan B.

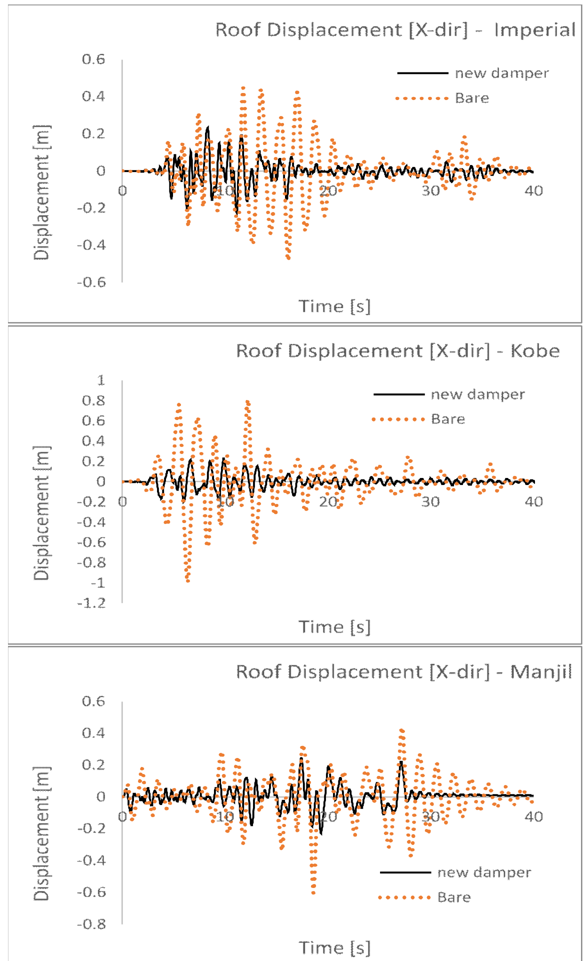

Fig. 13. Roof Displacement in the 15-story structure - Plan A – using BSD

However, by examining the results related to the base shear, as can be seen (Fig.s 14 to 17), we see a slight decrease in the structures, which can be due to the high damping of the dampers. Also, this slight decrease can be due to a significant increase in the stiffness of the structure and a decrease in the period, which indicates the need to pay attention to the standard design spectra in the design of the structure. It seems that the effect of dampers in reducing the maximum base shear parameters in short and medium structures is more than in tall structures.

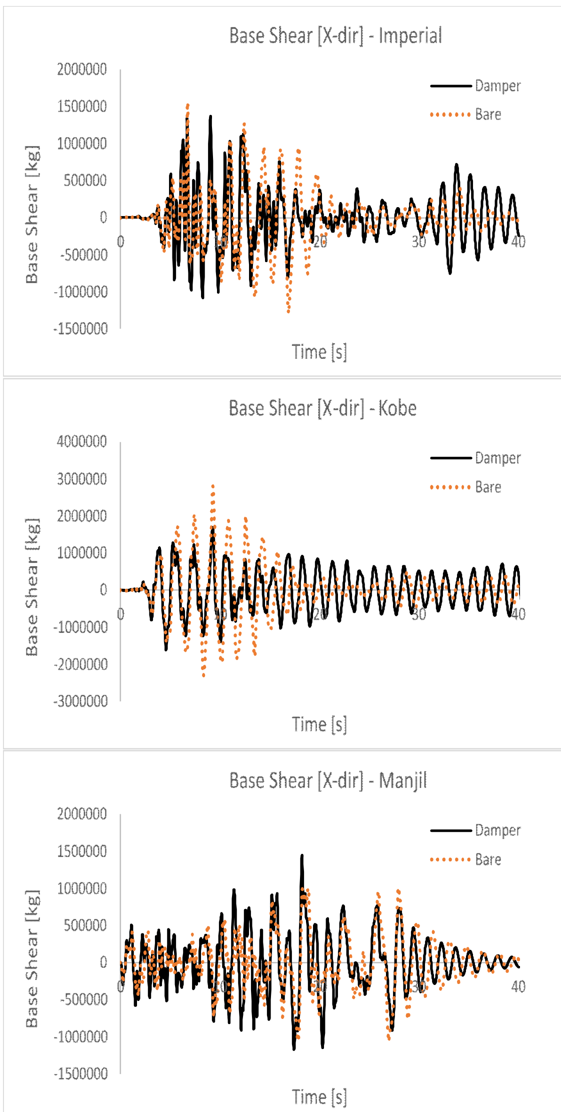

Fig. 14. Comparison of base shear in 15-story structure - Plan A.

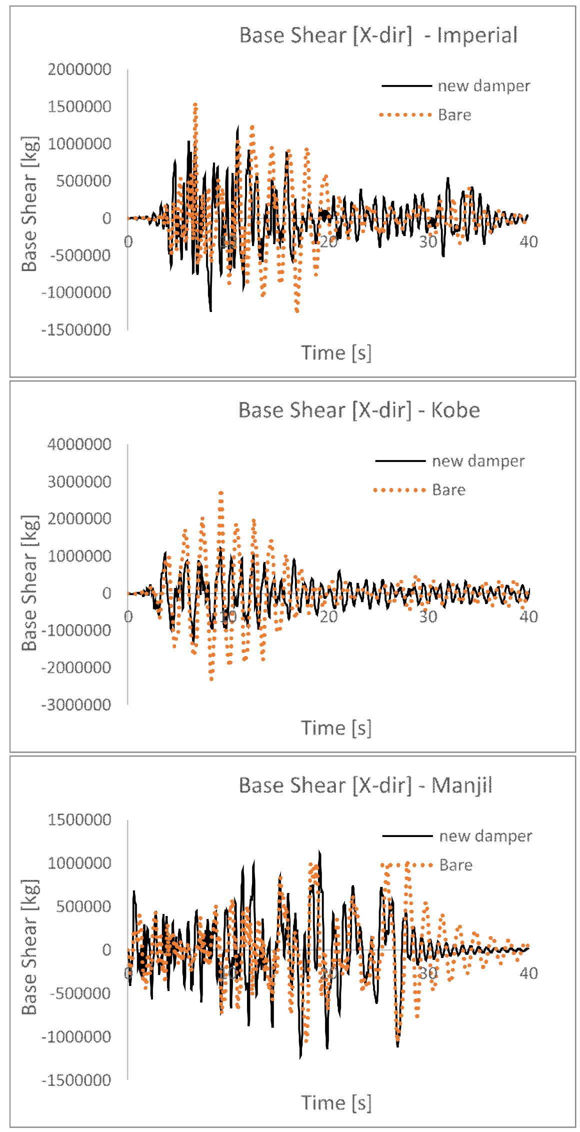

Fig. 15. Comparison of base shear in 15-story structure - Plan A – using BSD

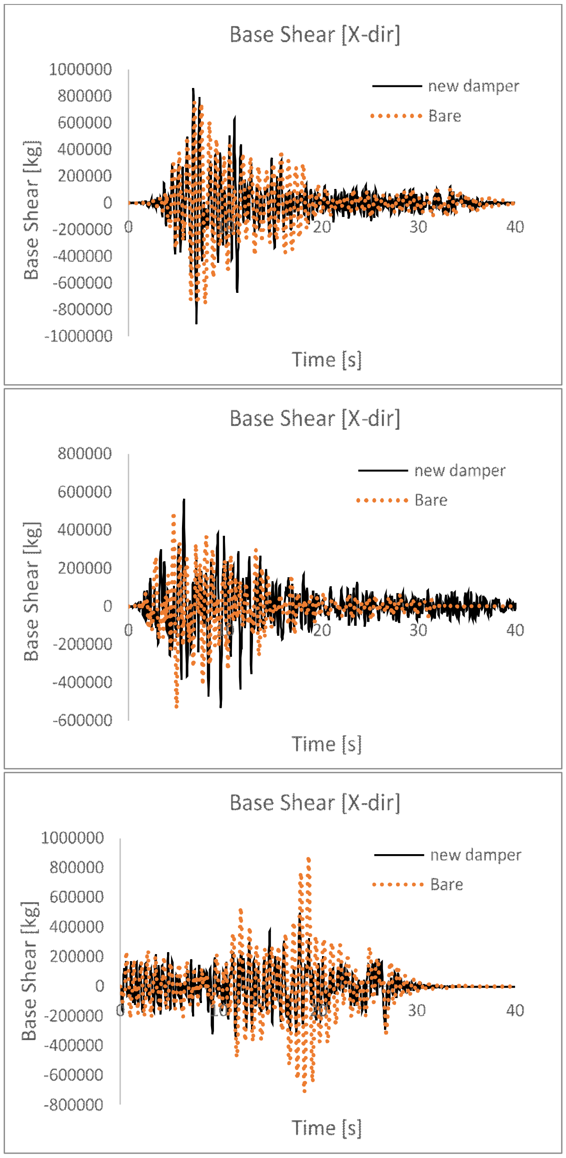

Fig. 16. Comparison of base shear in 5-story structure - Plan B - using BSD

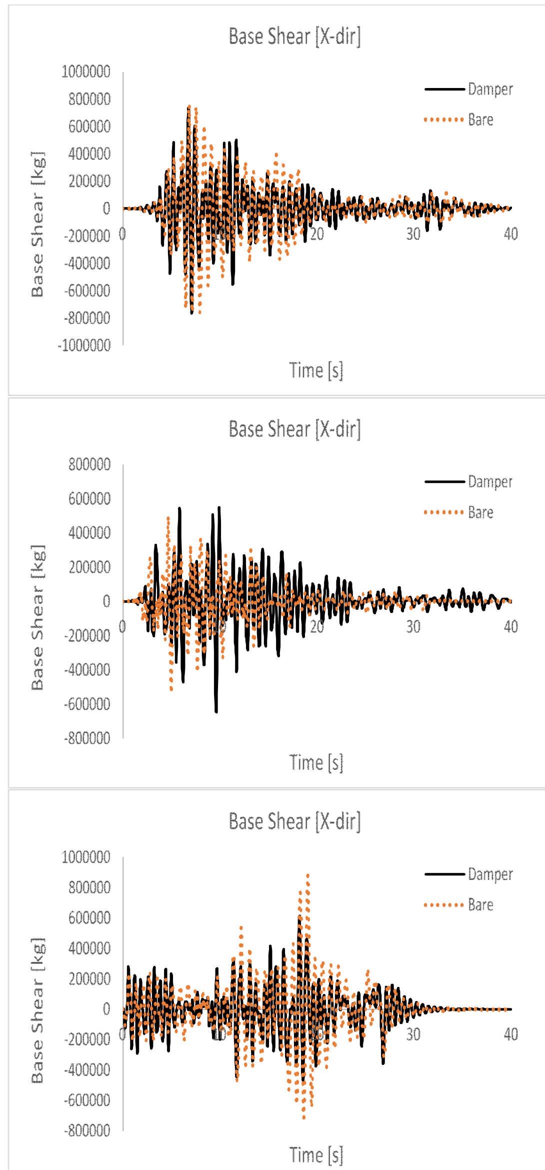

Fig. 17. Comparison of base shear in 5-story structure - Plan

As can be seen in seismic diagrams, in all three cases, roof acceleration, base shear and maximum displacement have damping effects, but this effect does not have a fixed trend, in other words, in short and medium structures with a more severe decreasing trend and in tall structures has a decreasing trend with a smoother slope and sometimes has increased responses.

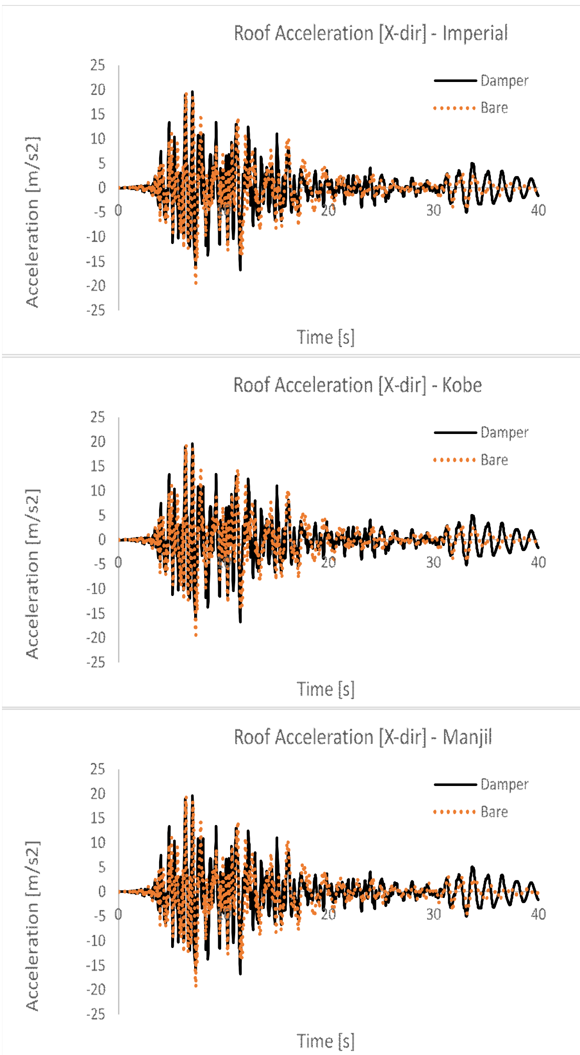

Fig. 18. Time history of roof acceleration in the 15-story structure - Plan A.

5. Conclusion and summary

This paper introduces a new multi-level pipe in the passive control system of the pipe and also a new diagonal brace-type slit damper, it was modelled in the software and after validation with the reference article according to all the pictures and descriptions of the section. Previously, the following results were obtained regarding the performance of the damper and its efficiency in four structures of 5, 10 and 15 floors with two different plans.

- It can be concluded that the effect of the damper in reducing the maximum displacement and drift of the roof story in short and medium structures will be more than tall structures. And this change for BSD has been very tangible and better than multi-level pipe damper.

- It seems that the effect of dampers in reducing the maximum base shear parameters in short and medium structures is more than tall structures.

- As can be seen in the seismic diagrams, in all three cases, the acceleration of the roof, the shear base, and the displacement of the maximum damping have positive effects, but this effect does not have a constant trend. The tall building has a decreasing trend with a smoother slope and sometimes has increased responses.

- It seems that reducing the periodicity of such structures according to the standard design has increased the responses. Therefore, paying attention to the standard design spectrum, as well as the frequency content of earthquakes, is of great importance in the design, which if not paid will reduce the efficiency of the damper.

- It should be noted that the success of the damper in reducing the base shear and displacement is much more significant than the reduction in acceleration, which can be justified due to the increase in structural stiffness, especially in the case of tall structures.

- Compared to these two dampers, in general, the BSD has better performance and using the damper in X, it has reduced the Time Period in this direction. Also, using this damper, story drift and roof displacement have lost more than 50 percent and amplitude structure is dramatically reduced.

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