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Sort Combination of Friction and Viscoelastic Dampers Effect on Behavior of Steel Moment Frames

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Abstract

Background/Objectives: In powerful earthquakes, the structure design is often such that the building is allowed an entrance into an inelastic position and as a result outbreak of persistent deformation. Therefore using appropriate energy absorption systems in structures with mal-functioned members is of high importance. **Methods/Statistical Analysis:** In the present research, a five-storey steel moment frame structure with the help of five different configuration modes for viscoelastic and friction dampers as connected diagonally, parallel and serially was examined. To examine the behavior of the structure, seven Accelerograms scaled by SAP were used. The structure was included in a dynamic nonlinear analysis. **Findings:** It was revealed that the existence of dampers causes a decrease in major responses of the structure including story displacement, story drift, story acceleration, base shear, and reduction of plastic joints function. Also, the parallel mode reflected better responses than the serial modes. **Conclusion/Application:** In conclusion, in this research we find that the friction damper had a better performance than the viscoelastic one due to higher stiffness.

Keywords: Friction Damper, Parallel Configuration, Serial Configuration, Steel Moment Frame, Viscoelastic Damper

1. Introduction and Background

The danger of earthquakes is always lurking behind all structures. Consequences of such a risk depending on the casualties caused by the structure destruction cannot be predicted. Although braced and non-braced frames as well as shear walls are economic and can control lateral deformations under the effect of winds and small earthquakes, during powerful earthquakes these structures will not show a desirable behavior, because, firstly, these structures are highly stiff and tend to attract more seismic forces. Secondly, their energy dissipation capacity severely drops due to damage to resistant elements during the earthquake load caused by reciprocating (hysteresis) motions and power dissipation is reduced very rapidly in next cycles. There is, therefore, a need for an energy dissipater that can dissipate the earthquake energy having not been affected by dynamic loading while being cost-effective is strongly felt. Dampers are among the main energy dissipating instruments in structures[1,2].

Modeling of an 18-storey building, installing a diagonal friction damper on storey 16 together with a diagonal viscoelastic damper on story1 as well as modeling of a 12- storey building, installing a diagonal friction damper on storey 11 together with a diagonal viscoelastic damper on storey 1 and performing historical analysis under different earthquakes on both models, Found that this mechanism significantly reduces the acceleration and displacement under all earthquakes[3].

Using ETABS on a12-storey concrete building with friction and viscous dampers performed the seismic analysis and compared the two dampers. The results showed that although the friction damper was much inexpensive than the viscous damper, its storey acceleration response was 25% more than that of the viscous damper[4].

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Goel and Booker performed a trial on a viscoelastic friction damper system and studied the effective parameters in its performance. The system included a friction damper with an extended viscoelastic unit and cost more than other dampers. The damper was easily built and installed in a short time without the need for experienced personnel at the desired location. The study of static and dynamic loads response helped the researchers identify the parameters affecting the building that the damper system led to their improvement. The numerical study also indicated that the overall response of the structure was mainly affected by damper properties such as geometry, friction glide moment and viscoelastic properties combined with the natural frequency of structures[5].

Also examined friction dampers behavior with high capacity in the tallest building in Japan. Based on a rotational friction damper theory the capacity of dampers was 1,500 to 5,000 kN. The dampers were designed for mechanical and thermal energy dissipation and protected the building against structural and non-structural damage of dynamic loads including earthquake and wind. Experimental results revealed that the dampers are very stable and are able to reach its projected capacity[6].

Nodeled two steel structures with a distance less than the allowable limit, in which viscoelastic damper can be used to strengthen and reduce the seismic response and eliminating the effects of the adjacent building's impact. SAP under 10 earthquake records was used. The results revealed that the period of building indicates a very little variation norm against damper stiffness variations, however, the hard frame period variations against damper stiffness variations is noticeable. In addition, the effect of viscoelastic dampers on the seismic response reduction was observed so that the impact of the two adjacent structures are completely dissipated within the half of the allowable limit adopted in Iranian 2800 Regulations where the response reduction was even less than the proportional amount observed in the mode where there is no connection to other frames maintaining or reducing the displacements of the two structures[7].

The necessity and importance of the present research, which aimed to examine the effect of combined friction and viscoelastic dampers configurations on steel moment frame behavior in order to obtain the greatest reduction in response of the structure under effect of seismic force, as the main objective of the study, has not been so far explored in other studies. This is also the fundamental innovation of the present study.

2. Relations on the Dampers

2.1 Friction Dampers

These dampers dissipate the earthquake energy through friction of contact levels. Energy dissipation in the instruments is dependent on its relative internal power and displacement. Therefore, they are modeled via force hysteresis- deformation relations. Force-deformation behavior models of these dampers (elastoplastic models) are presented in Figure 1[8–10].

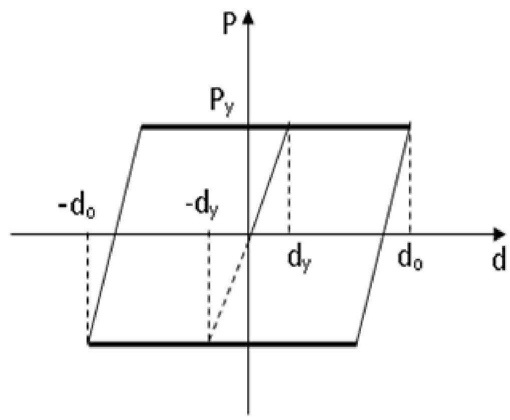

Figure 1. Cyclic behavior of elastoplastic models.

Energy dissipation per cycle (E) is equivalent to the hysteresis loop among points (d_0, P_y) and ($-d_0$, $-P_y$), calculated via relation [1].

$d_0 \geq d_y$ $\qquad E = 4P_y\,(d_0, -d_y)$ [1]

d: Damper displacement, d_y : Damper yield displacement, P_y : Damper yield force.

2.2 Viscoelastic Damper

These dampers are used in structures with few degrees of freedom using Maxwell's analytic model, in which each damper stiffness and damping are serially modeled where the spring represents the stiffness and K_b and C_d denote stiffness and damping respectively.

K_b: Bracing stiffness value, C_d : Damping value, : Damper force.

The energy absorbed by the damper according to Equation [2] is as follows:

$F = C.V^N + K_b\Delta$ [2]

F: Damping force, C: An arbitrary constant that remains constant during the velocity interval, V: Velocity, Δ: Displacement of the ends of the damper, N: The power that can vary between 0.3 and 1.95 which remains constant during the velocity interval (Figure 2).

Figure 2. Viscous damper analytic model.

3. The Process of Modeling and Hypotheses

3.1Modeling of the Frame

In this paper, a three span medium moment with a span of five meters and on five storeys was used. Then, in the middle span of the frame five different configuration modes for friction dampers and viscoelastic dampers was used. The structural design was tried to be optimal as much as possible and the stress ratio for of all members to be smaller than one. The sections are shown in Figure 3.

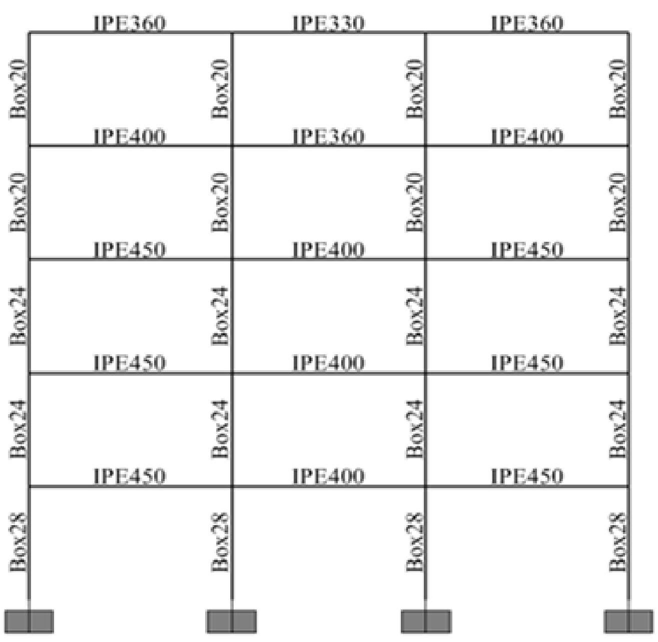

Figure 3. Designed sections.

3.2 Dampers Configuration

In Figure 4, the modes used in this study and the dampers configurations in the middle span are provided. In the middle span of the frame five different modes of configurations for friction and viscoelastic dampers are used.

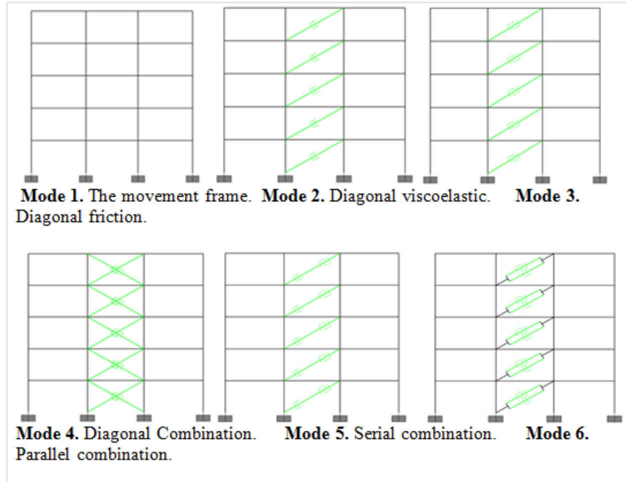

Figure 4. Dampers configuration.

3.3 Selecting Accelerograms

Accelerograms that are selected for designs should resemble strong ground movements which may possibly occur in the region under examination in terms of frequency content, spectral response and duration (time). In the present study seven pairs of scaled Accelerograms were used and structures were analyzed non-linearly. To get the final solution, the responses of all the seven Accelerograms were averaged. Table 1 presents the records used in this paper[11,12].

Table 1. The applied records

No	Earthquake name	Date	PGA
1	Elsentro	1976/05/17	0.6438
2	Tabas	1978/09/16	0.836
3	Superstition Hills	1987/11/24	0.682
4	Manjil	1990/06/20	0.510
5	Northridge	1994/01/17	0.6615
6	Kobe	1995/01/16	0.7069
7	LomaPrieta	1989/10/18	0.7835

4. Results

4.1 Mean Maximum Storey Displacement

At any moment, any displacement is recorded by an Accelerogram on each storey. During the application of each Accelerogram, in a moment, the displacement of the storey is maximized. This maximum displacement in each Accelerogram occurs at a different time. Averaging the maximum displacement of each storey in different

Accelerograms yields the maximum displacement of the storeys. In Figure 5, the mean maximum displacement of storeys in each mode of damper arrangement is presented. In addition, the mean displacement values of all 6 configuration modes are compared.

Looking carefully at the figures, it could be argued that: In all models the existence of dampers reduced the maximum storey displacement .The maximum displacement of storeys in Mode 3 (diagonal friction), Mode 4 (diagonal friction with diagonal viscoelastic) and Mode 6 (parallel combination of friction and viscoelastic dampers) is quite the same and larger than other scenarios. In other words, the friction damper seems sufficient and the viscoelastic damper does not help, since in the parallel mode the stiffer damper is more effective. Mode 5 (serial combination of two dampers) and Mode 2 (diagonal viscoelastic damper) are quite the same and less effective in reducing the responses.

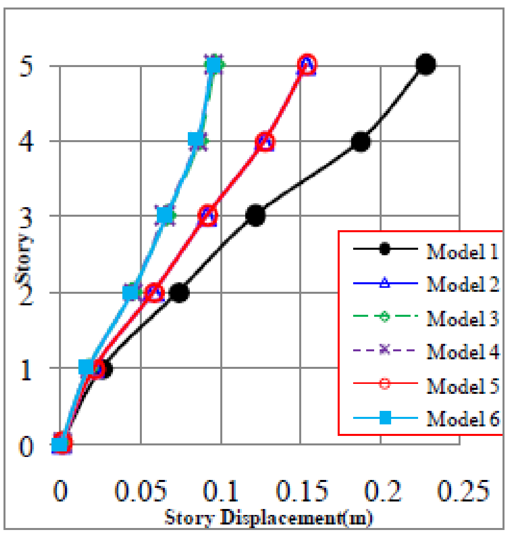

Figure 5. Mean maximum storey displacement.

4.2 Mean Maximum Storey Drift

In Figure 6, the mean drift values of storeys for all 6 modes are compared. Looking carefully at the figures, it could be argued that: In all models the existence of dampers reduced the maximum storey drift .The existence of dampers causes a reduction in storey drift by less than 0.015% which appropriately meets the criteria for drift control regulations. The maximum drift of storeys in Mode 3 (diagonal friction), Mode 4 (diagonal friction with diagonal viscoelastic) and Mode 6 (parallel combination of friction and viscoelastic dampers) is quite the same and larger than other scenarios. In other words, the diagonal friction damper seems sufficient and the viscoelastic damper does not help, since in the parallel mode the stiffer damper is more effective. Mode 5 (serial combination of two dampers) and Mode 2 (diagonal viscoelastic damper) are quite the same and less effective in reducing the responses.

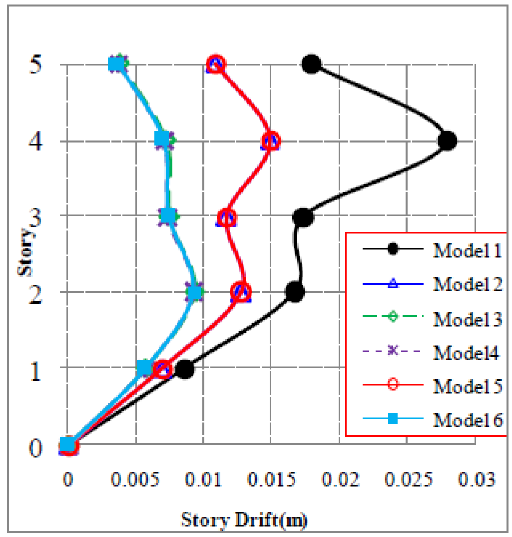

Figure 6. Mean maximum storey drift.

4.3 Mean Maximum Storey Acceleration

Reducing the storey acceleration is significant for improving the performance of non-structural members. In Figure 7, the mean acceleration values of storeys for all six modes are compared.

Looking carefully at the figures, it could be argued that: In all models the existence of dampers reduced the maximum storey acceleration. The maximum acceleration of storeys in Mode 3 (diagonal friction), Mode 4 (diagonal friction with diagonal viscoelastic) and Mode 6 (parallel combination of friction and viscoelastic dampers) is quite the same and larger than other scenarios. In other words, the diagonal friction damper seems sufficient and the viscoelastic damper does not help, since in the parallel mode the stiffer damper is more effective. Mode 5 (serial combination of two dampers) and Mode 2 (diagonal viscoelastic damper) are quite the same and less effective in reducing the responses.

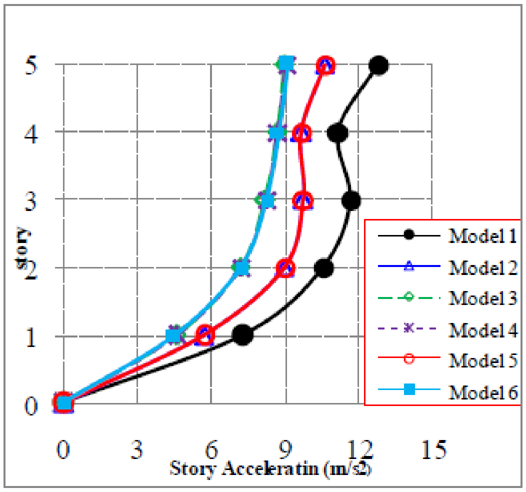

Figure 7. Mean maximum storey acceleration.

4.4 Mean Maximum Base Shear

In Figure 8, the mean acceleration values of storeys for all six modes are compared. Looking carefully at the figures, it could be argued that: In all models the existence of dampers reduces the maximum base shear. In all modes, the base shear has been reduced almost the same.

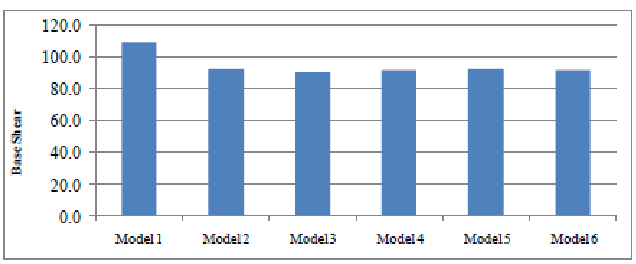

Figure 8. Mean maximum base shear.

4.5 Plastic Joints

In analysis and design of steel frames, plastic joint formation is important. The plastic joint is a point in the structure, the moment of which immediately converges to zero due to the plastic moment impact leading to the instability of the structure. In fact the plastic joint in steel structures is a section with saturated cords.

In the following figure (Figure 9), the durable plastic joints of the members after the earthquake under different configurations of dampers are shown. Looking carefully at the figures, it could be argued that: All the configurations led to reduction of plastic joint functions. The friction damper (Mode 2) had a greater impact on reducing the level of plastic joints function to the viscoelastic damper (Mode 3), since the friction damper is stiffer than the viscoelastic damper. In Mode 3 (diagonal friction), Mode 4 (diagonal friction with diagonal viscoelastic) and Mode 6 (parallel combination of frictional and viscoelastic dampers) all plastic joints of the structure were removed and the behavior of the structure was linear.

In other words, the diagonal friction damper seems sufficient and the viscoelastic damper does not help, since in the parallel mode the stiffer damper is more effective. Mode 5 (serial combination of the two dampers) and Mode 2 (diagonal viscoelastic damper) reflected as less effective in reducing the responses, since the softer damper is more effective in these modes .In other words, in some members very few little plastic joints are produced.

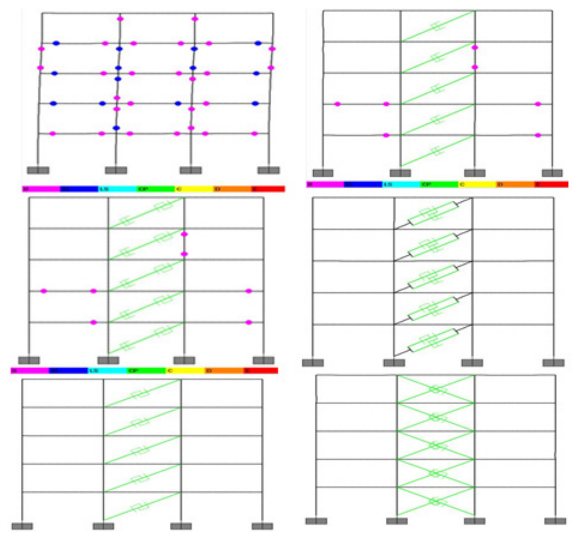

Figure 9. Plastic joints.

5. Conclusion and Summary

In all modes, the existence of dampers causes a decrease in major responses of the structure including storey displacement, storey drift, storey acceleration, base shear and reduction of plastic joints function. Generally, the behavior of Mode 3 (diagonal friction), Mode 4 (diagonal friction with diagonal viscoelastic) and Mode 6 (parallel combination of friction and viscoelastic dampers) is quite the same, since in parallel modes, friction dampers dissipate the largest share of energy due to higher stiffness resulting in the behavior of parallel modes to be as Mode 2. Generally the behavior of configurations in Mode 2 (diagonal viscoelastic damper), Mode 5 (serial combination of friction damper and viscoelastic damper) is quite the same, since in serial modes, viscoelastic dampers dissipate the largest share of energy due to higher soft ness resulting in the behavior of serial modes to be as Mode 2.

In general, friction dampers and diagonal and parallel modes (Modes 3, 4 and 6) showed better behavior than viscoelastic dampers in parallel and serial modes (Modes 2 and 5). This is caused by higher stiffness of friction dampers. In almost all modes dampers have a hysteresis cycle and lead to energy dissipation. In almost all modes, the existence of dampers eliminates all or a large part of plastic joints of steel frames with.

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