

Evaluation of Friction-Slit Hybrid Dampers in Moment - Resisting Steel Frames

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ABSTRACT

This paper investigates the friction-slit hybrid dampers with two different behaviors in the moment-resisting steel frames. For this purpose, 5, 10 and 15 stories, models of steel construction frames have been considered, and the mentioned also dampers have been added as a brace. These structural models were subjected to nonlinear static analyzes (pushover) and nonlinear dynamic analysis (time history) using seven pairs of far-field records. Nonlinear behavior and response in the analysis were also considered by applying nonlinear characteristics for the dampers in the frame and by assigning plastic hinges to structural members. Therefore, the probability of failure decreases. Based on the numerical results, adding this damper to the frame, reduces drift by 33% the maximum displacement of the roof by 23% in pushover analysis, and reduces displacement, velocity and acceleration by 60%, 70% and 45%, and ultimately reduces the kinetic energy by 51% in time history analysis.

Keywords: Earthquake, Seismic Analysis, Nonlinear analysis, Damper, Steel Frame, Displacement, Plastic Hinges.

1. INTRODUCTION

Recently, two of the most abundant energy dissipation devices used in building structures are friction and metallic fluid dampers. Energy dissipation devices have various shapes, such as ADAS [1], adding damping and adding stiffness, resistant buckling braces [2] and slit dampers [3]. Among the metal dampers, the slit steel plate dampers are advantage to the other dampers, due to their easy design and construction [4-8]. Friction dampers used in various forms have been used by [9], and [10]. Recently, [11] expanded friction dampers by friction created between low-alloyed materials and softened steel. Energy dissipation devices and inactive dampers are used to greatly enhance seismic of structures. Some researchers also investigate the simultaneous use of these tools to increase energy dissipation capacity. For example, [12-14] studied hybrid tools. These devices are displacement-dependent and velocity-dependent to reduce seismic of structures and minimize the faults of the dampers which are used individually. [15] studied the effect of hybrid friction-viscoelastic dampers with the placement of these dampers between the shear wall and showed that the seismic responses of the structures, when these dampers are placed in the structure.[16] studied hybrid systems, which were composed of resistant buckling braces and viscous fluid tools, and investigated the seismic responses of structures. They also studied the optimal design methods for composite dampers that were made up of a combination of resistant buckling braces and viscous fluid tools, and investigated the seismic responses of structures. Optimal design methods for hybrid or multiple dampers were developed by [17-18]. They investigated the effect of these hybrid tools, consisting of slit and friction dampers, in reducing the seismicity of structures in small and large earthquakes. [19] investigated the hybrid effect of shear-type friction dampers and slit dampers with non-uniform tapes in seismic protection for different levels of energy.[20] studied combined dampers consisting of friction and split dampers in response to small and large earthquakes. Previous results have shown the ability of inactive hybrid systems to improve the reaction of structures to conventional systems. The purpose of this study is to investigate the behavior of hybrid dampers in steel structures. For this purpose, the behavior of the moment resisting steel frames of the structures in the original state and equipped with a hybrid damper, with two different behaviors is analyzed and investigated. In addition to the nonlinear behavior due to the presence of dampers, in both cases, the nonlinear behavior of frame members can also occur through the assignment of plastic hinges to see more realistic behavior of the models.

2. SLIT- FRICTION HYBRID DAMPER

The hybrid dampers are formed from a combination of friction and split dampers. The steel plate of slit dampers consists of a large number of strips, where these strips with the same sizes has been shown in Figure 1. Stiffness and yielding strength of plate strips can be obtained according to the following equations 1 and 2 [20]:

$$K_s = n \frac{12EI}{l_0^3} = n \frac{Etb^3}{l_0^3} \tag{1}$$

$$P_{ys} = \frac{2nM_p}{l_0} = \frac{n\sigma_y tb^2}{2l_0} = \frac{n\sigma_y tb^2}{2l_0} \tag{2}$$

Where “n” is the number of stripes, “t” is the thickness of the strips, “b” is the width of the strips and “l₀” is equal to the vertical length of the strips. The friction damper starts its function when the applied load comes to the sliding force. The initial stiffness of the rotational friction dampers is very large, and its yielding strength is obtained according to the following equation 3 [20] :

$$P_{yf} = 2\mu NQ \frac{R_m}{L_0} \tag{3}$$

According to the equation 3, “L₀”is the length between two stripe plates, “μ” is the coefficient of friction of the plate, “N” is the number of friction surfaces, “Q” is the clamping force, “R_m” is the effective area of the friction surface. Friction and split dampers are connected in parallel. In this case, the initial stiffness and yielding strength of hybrid damper is obtained according to experimental results, that display in table.1. In this paper, the hybrid damper behavior includes type of Rubber Isolator element and the Plastic Wen element, which is modeled by ETABS, 2016 software [21]. These dampers have been added as a brace in moment- resisting steel frames, the joints of the upper and lower plates of the dampers to the beam and brace can be in the form of screws or welded joints that screws joints have the advantage of more easily replacing the device after severe earthquakes.

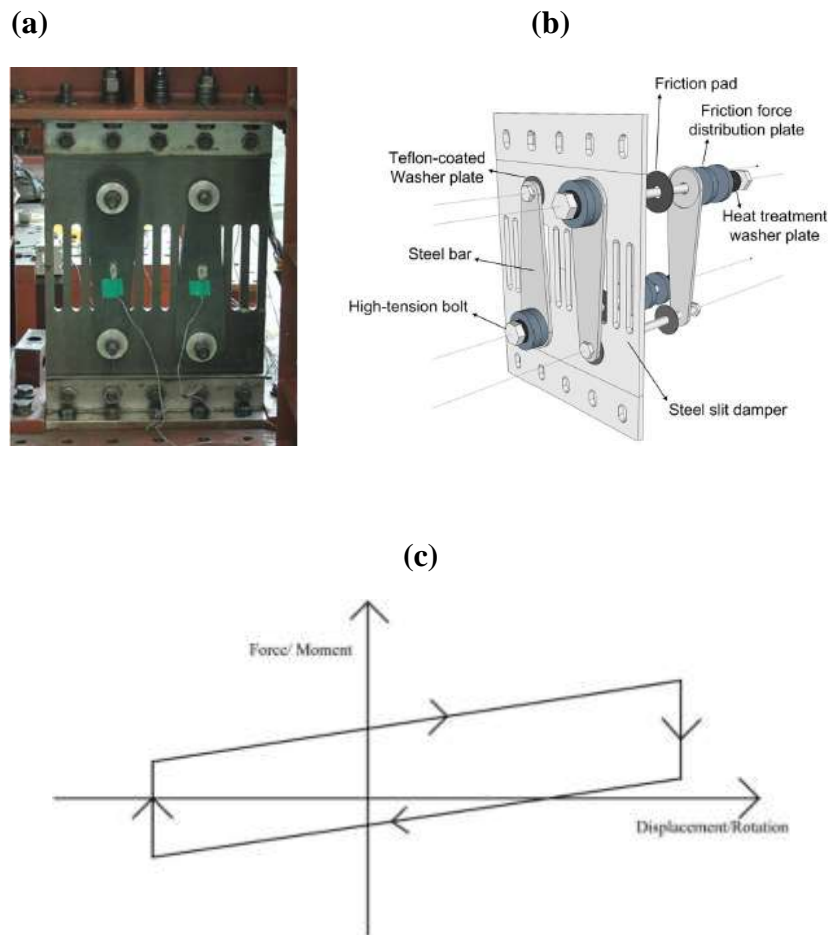
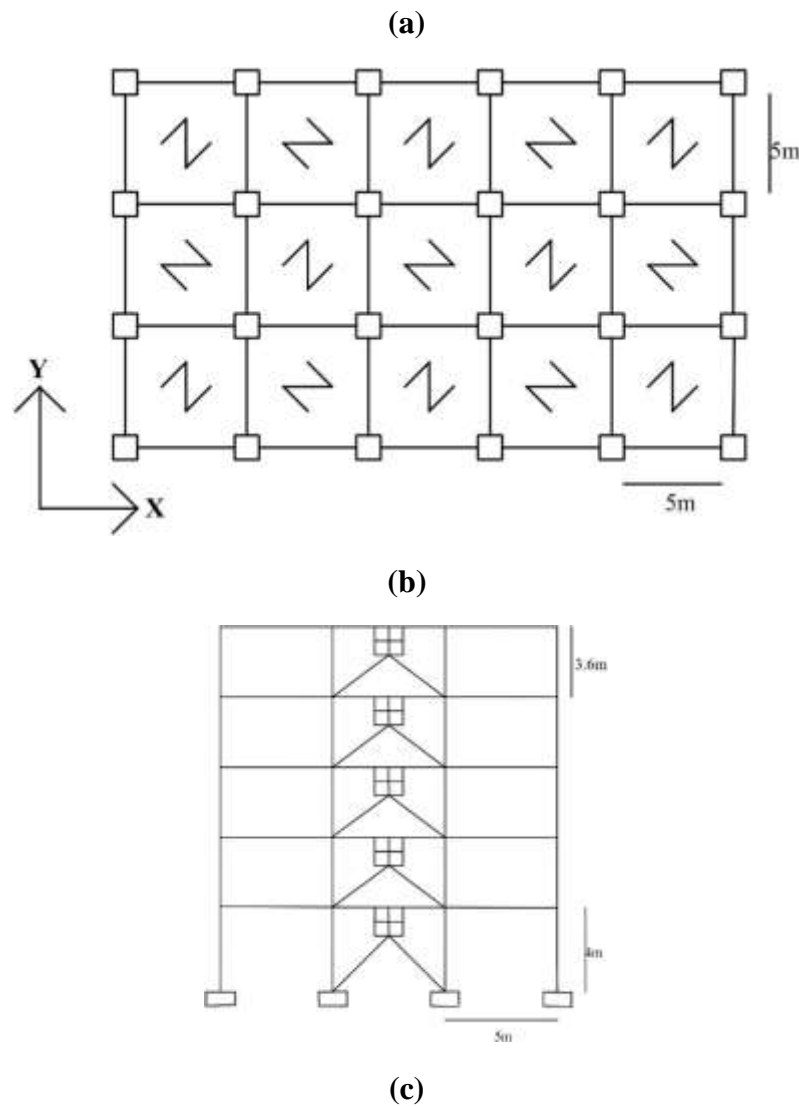
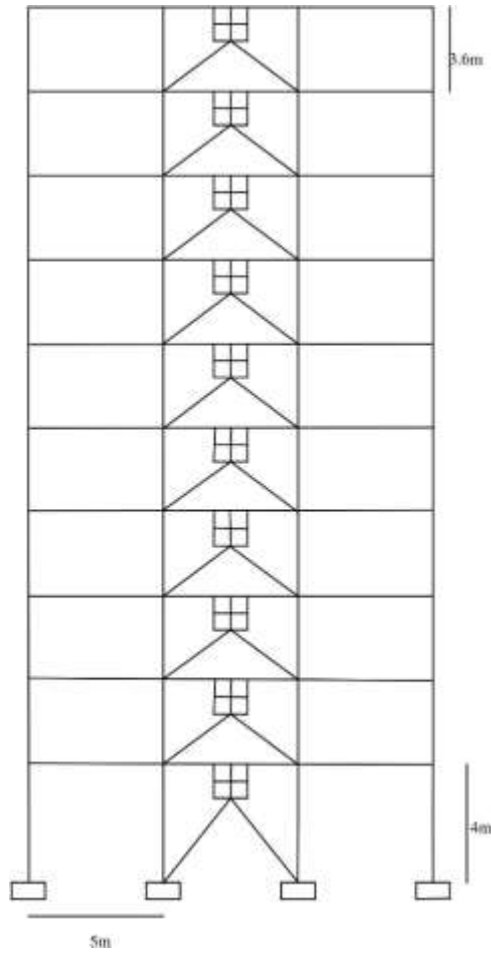


Figure 1. The SFHD in laboratory: (a) Hybrid Damper; (b) Schematic picture of the SFHD; (c) Bilinear curve [20].

3. MODELING AND ANALYSIS ASSUMPTIONS

Structural models used in this research are considered as moment-resisting steel frames, with moderate ductility. The number of stories are 5, 10 and 15, each of them has 5 bays of 5 m, in X direction and 3 bays of 5 m, in Y direction, and the dampers are placed between the upper ends of the braces and the lower part of the beam in the frames. The height of the first story is 4m and the other stories are 3.6m, and it is assumed that the connection are fixed connection. The sections used for columns and braces are BOX and for IPE beams, are shown in Tables (2, 3, 4), the geometry of the frames used together with the sections of its members is shown in Figure 2. Amount of the dead load, live load, live load of the roof, snow load and partition load are 600kg/m², 240kg /m², 96kg /m², 196kg /m² and 126kg /m² in the design of frames, respectively. Seismic loading for initial analysis and design is based on the ASCE07, 2016 code [22]. The loading bearing of the roof steel decking type. Critical damping ratio in the structure is 5%, soil is of D type, construction site is in Montana State. In structures with hybrid dampers, cause to the frame members remains in the form of elasticity and only the damper enters into the nonlinear zone. After initial design of the frames with mentioned loading, a nonlinear static analysis (pushover) and nonlinear time analysis (time history) was performed by software ETABS2016 to study the behavior of frames without damper and equipped with a damper during an earthquake. For this purpose use seven pairs of far-filed were used according to the FEMA-P695, 2009 [23] , which has been shown in Table 5. In nonlinear static analysis, two combinations of 1.1DL + 0.75LL and 0.9DL loads have been used in both X and Y directions, and nonlinear time histories analysis is considered as a direct integration. Damping of the structure (other than the adjunct damper) has been considered as in a damping proportional to mass and stiffness (Riley assumption) with damping ratio of 5%.





(d)

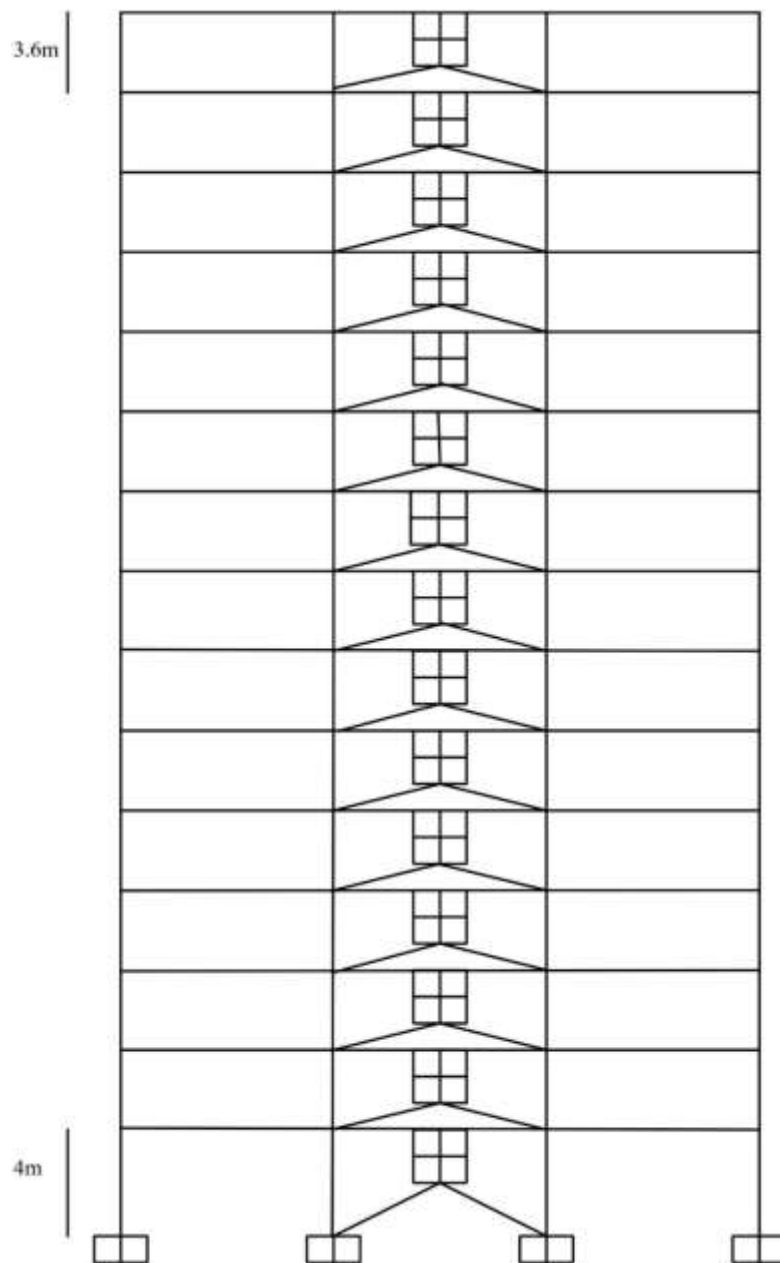


Figure 2. Schematic Geometry of the used frames: (a) Plan of the structure; (b) Elevation of 5 stories structure; (c) Elevation of 10 stories structure; (d) Elevation of 15 stories structure

Table 1 Properties of the friction damper, the slit damper and the hybrid damper from experiments and analytical models [20].

	Theoretical values	Experimental results
$(\delta_{y, friction}, P_{y, friction})$	(0mm, 37.5 kN)	(0.8mm, 37.8 kN)
$(\delta_{y, slit}, P_{y, slit})$	(1.6 mm, 48.75 KN)	(3.0mm, 46.7KN)
(δ_{max}, P_{max})	(65.0 mm, 124.8 KN)	(63.38 mm, 120.0 Kn)
K_{SE} , Elastic stiffness of slit dampers	30.66 Kn/mm	15.57 kN/mm
K_{Sp} , Post-yield stiffness of slit dampers	0.61 kN/mm	0.60 KN/mm

Table 2. Section size of the 5 stories model structure.

Applied sections			
Number of the stories	Columns	Beams	Braces
First story	BOX:250*250*20	IPE330	BOX:120*120*10
Second story	BOX:250*250*20	IPE330	BOX:120*120*10
Third story	BOX:200*200*20	IPE300	BOX:120*120*10
Fourth story	BOX:200*200*20	IPE300	BOX:120*120*10
Fifth story	BOX:180*180*20	IPE240	BOX:120*120*10

Table 3. Section size of the 10 stories model structure.

Applied sections			
Number of the stories	Columns	Beams	Braces
First story	BOX:350*350*20	IPE360	BOX:180*180*10
Second story	BOX:350*350*20	IPE360	BOX:180*180*10
Third story	BOX:350*350*20	IPE360	BOX:180*180*10
Fourth story	BOX:350*350*20	IPE360	BOX:180*180*10
Fifth story	BOX:330*330*20	IPE330	BOX:180*180*10
Sixth story	BOX:330*330*20	IPE330	BOX:180*180*10
Seventh story	BOX:330*330*20	IPE300	BOX:180*180*10
Eighth story	BOX:330*330*20	IPE300	BOX:180*180*10
Ninth story	BOX:300*300*20	IPE270	BOX:180*180*10
Tenth story	BOX:300*300*20	IPE270	BOX:180*180*10

Table 4. Section size of the 15 stories model structure.

Applied sections			
Number of the stories	Columns	Beams	Braces
First story	BOX:450*450*25	IPE400	BOX:200*200*10
Second story	BOX:450*450*25	IPE400	BOX:200*200*10
Third story	BOX:450*450*25	IPE400	BOX:200*200*10
Fourth story	BOX:400*400*25	IPE360	BOX:200*200*10
Fifth story	BOX:400*400*25	IPE360	BOX:200*200*10
Sixth story	BOX:400*400*25	IPE360	BOX:180*180*10
Seventh story	BOX:350*350*20	IPE330	BOX:180*180*10
Eighth story	BOX:350*350*20	IPE330	BOX:180*180*10
Ninth story	BOX:350*350*20	IPE330	BOX:180*180*10
Tenth story	BOX:300*300*20	IPE300	BOX:180*180*10
Eleventh story	BOX:300*300*20	IPE300	BOX:160*160*10
Twelfth story	BOX:300*300*20	IPE300	BOX:160*160*10
Thirteenth story	BOX:250*250*15	IPE270	BOX:160*160*10
Fourteenth story	BOX:250*250*15	IPE270	BOX:160*160*10
Fifteenth story	BOX:250*250*15	IPE270	BOX:160*160*10

Table 5. seven pairs of far-field acceleration records [23]

PEER-NGA Records Information					Recorded Motions	
ID No.	Record Seq. No.	Lowest Freq(HZ)	Component 1	Component 2	PGA_{max} (g)	PGV_{max} (cm/s)
1	169	0.06	IMPVALL/H-DLT262	IMPVALL/H-DLT352	0.35	33
2	174	0.25	IMPVALL/H-E11140	IMPVALL/H-E11230	0.38	42
3	752	0.13	LOMAP/CAP000	LOMAP/CAP090	0.53	35
4	767	0.13	LOMAP/G03000	LOMAP/G03090	0.56	45
5	848	0.13	LANDERS/CLW-LN	LANDERS/CLW-TR	0.42	42
6	900	0.07	LANDERS/CLW-YER270	LANDERS/CLW-YER360	0.24	52
7	953	0.25	NORTHR/MUL009	NORTHR/MUL279	0.52	63

4. NUMERICAL RESULTS

4-1. Pushover analysis outcome

The development of the nonlinear static analysis also called the pushover analysis, originated as simplified performance evaluation tool. Pushover analysis uses height-wise lateral load distribution pattern considering the contribution of higher modes as in the modal pushover analysis to calculate the inelastic seismic demands of the structure [24]. Static pushover analysis provides advantageous data on the lateral strength and ductility of structures [25].

4-1-1. Drift

In Figure 3, drift has been shown according pushover analysis in 5, 10 and 15 stories. According to this analysis, drift of structures equipped with hybrid damper with Rubber Isolator behavior is better than structures equipped with hybrid damper with Plastic Wen behavior and also performance of structures retrofitted with slit and friction dampers, mostly are similar together. The reduce of drift in structure equipped with hybrid damper with Rubber Isolator behavior is in 5 story 33%, in 10 story 28% and in 15 story 37% in compered with original structures.

4-1-2. Roof Displacement

Figure 4, show the roof displacement in structures 5, 10, and 15 stories under pushover analysis, it can be seen that in structures equipped with a hybrid damper (with Rubber Isolator behavior), the displacement of the roof has decreased in 5 story 20%, in 10 story 16% and in 15 story 33% compared with the structure without a damper, and the performance of the structures equipped with a hybrid damper (with Rubber Isolator behavior) is so better than the structures equipped with friction, slit and hybrid (with plastic wen) due to the effective damping coefficient in the modeling of the hybrid damper (with Rubber Isolator behavior). Decrease in roof displacement reduces structural element and non-structural element damages and plastic rotations.

5. TIME HISTORY ANALYSIS

Nonlinear dynamic analyses were conducted on the 5, 10 and 15 stories under 7 pairs of a far- filed ground motions.

5-1. Displacement of the structure

Figure 5, is shown the displacement of the structure under the Imperial Valley earthquake. According to the diagrams, the displacement of the structure in structures equipped with hybrid, friction and split dampers, with two types of the Rubber Isolator and plastic wen behavior, has decreased by 80% in 5 story, by 69% in 10 story and by 30% in 15 story, than original structures, it is observed that all dampers have the same function.

5-2. Velocity of the structure

Figure 6, shows the velocity of structure under the Imperial Valley earthquake. The velocity of structure, in structures equipped with hybrid, friction, and slit dampers with two types of the Rubber Isolator and Plastic Wen behavior has decreased by 75% in 5 story, by 63% in 10 story and by 70% in 15 story than the original structures, that is shows all dampers have the same function.

5-3. Acceleration of structure

Figure 7 shows the acceleration of structure under the Imperial Valley earthquake the acceleration of structure in structures with hybrid, friction, and slit dampers with two types of the Rubber Isolator and Plastic Wen behavior has decreased by 33% in 5 story, by 57% in 10 story and by 46% in 15 story than the original structures, that is shows all dampers have the same function.

5-4. Kinetic energy of structure

Figure 8, shows the kinetic energy of structure under the Imperial Valley earthquake. According to the curves, the kinetic energy of structure in structures, equipped with hybrid, friction, and slit dampers with two types of the Rubber Isolator and plastic wen behavior has decreased by 51% in 5 story, by 42% in 10 story and by 62% in 15 story than the original structures, that it shows all hybrid dampers (with Rubber Isolator behavior) have better function than other dampers.

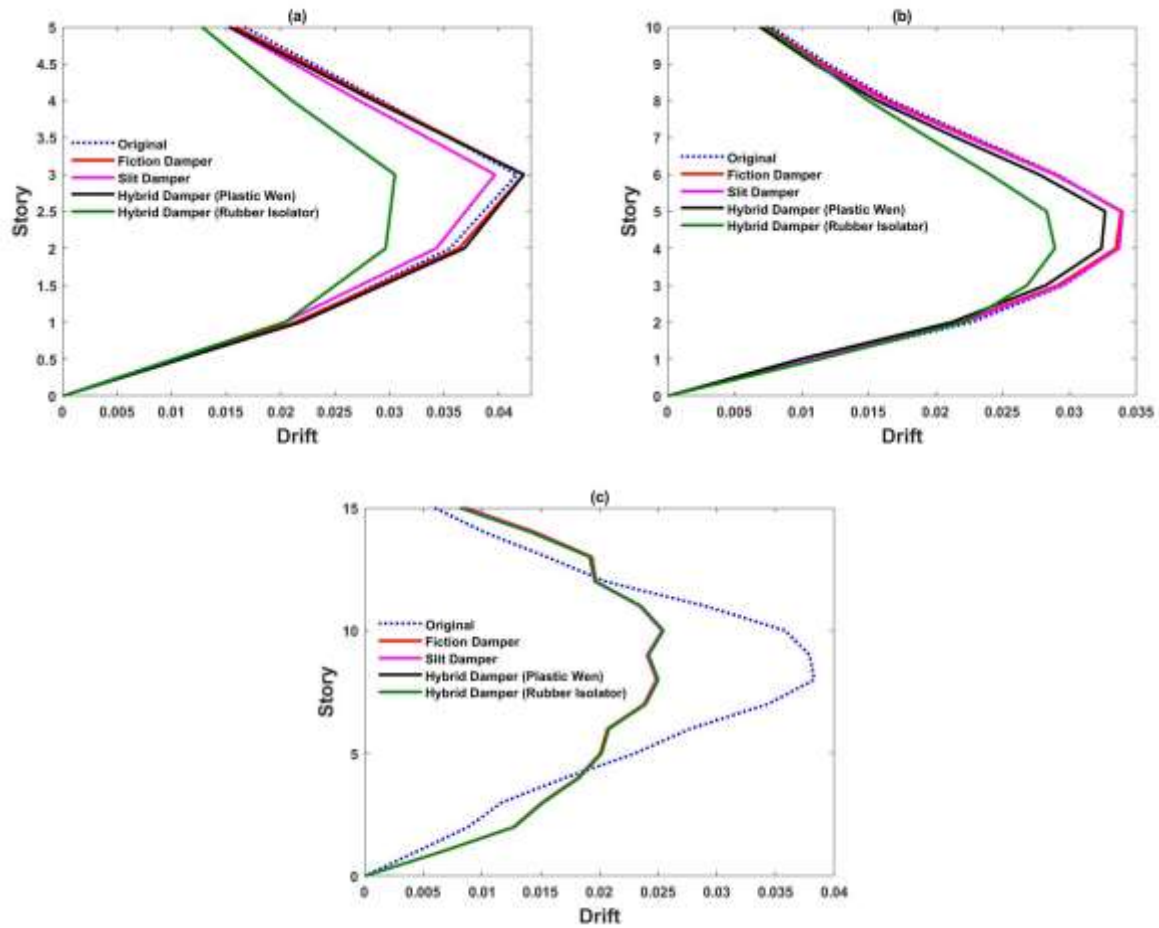
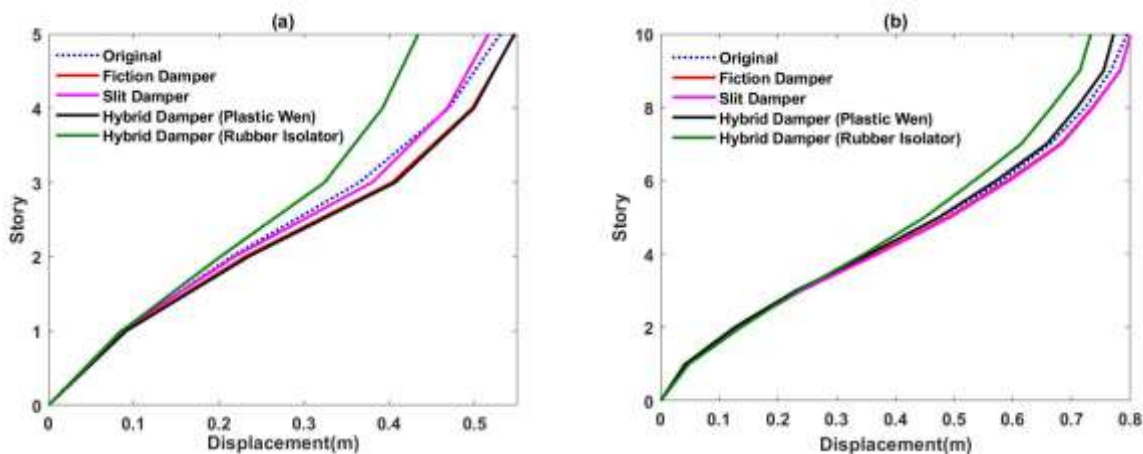


Figure 3. Drift: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure



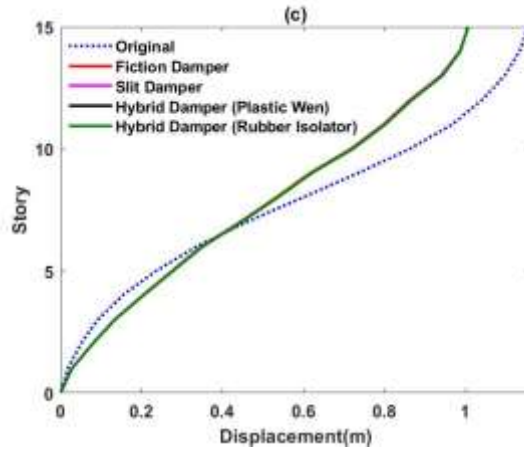


Figure 4. Displacement of roof: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure

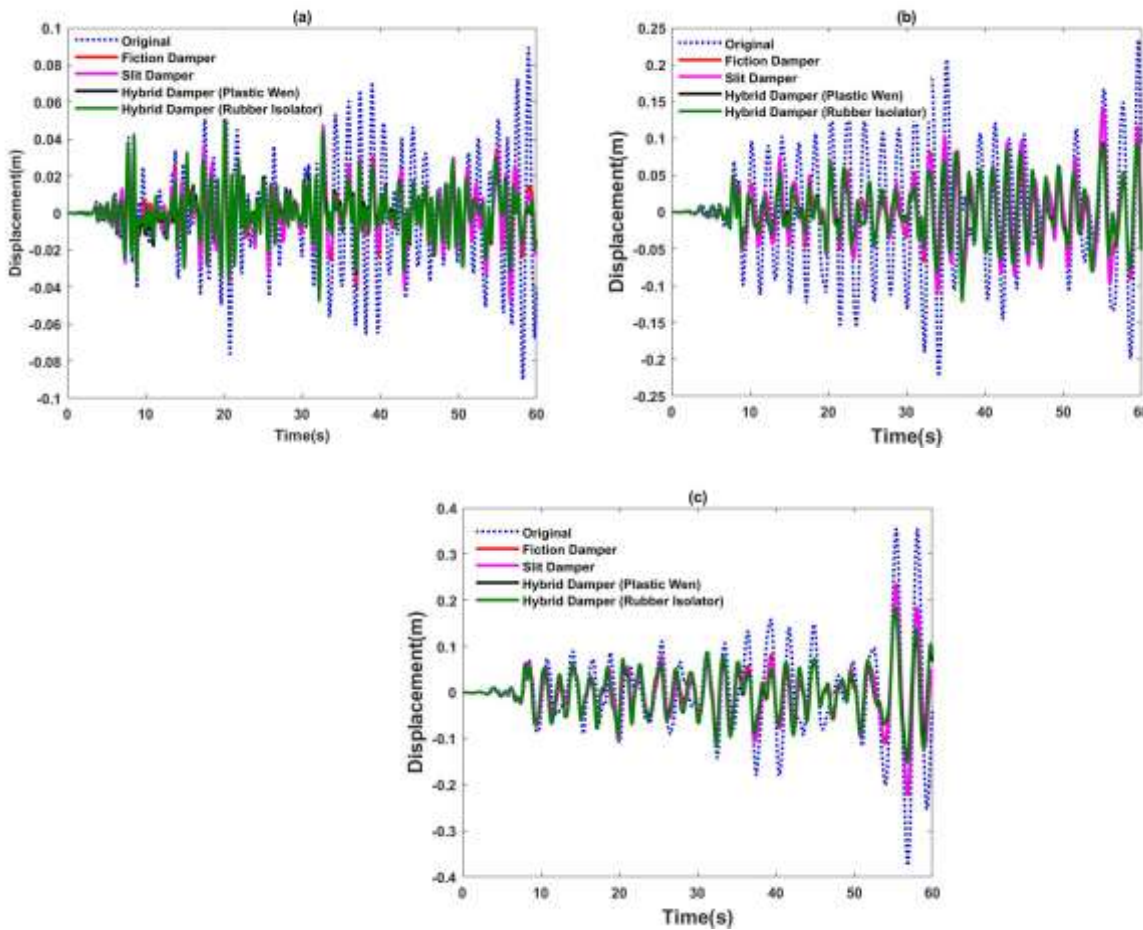


Figure 5. Displacement of the structure: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure

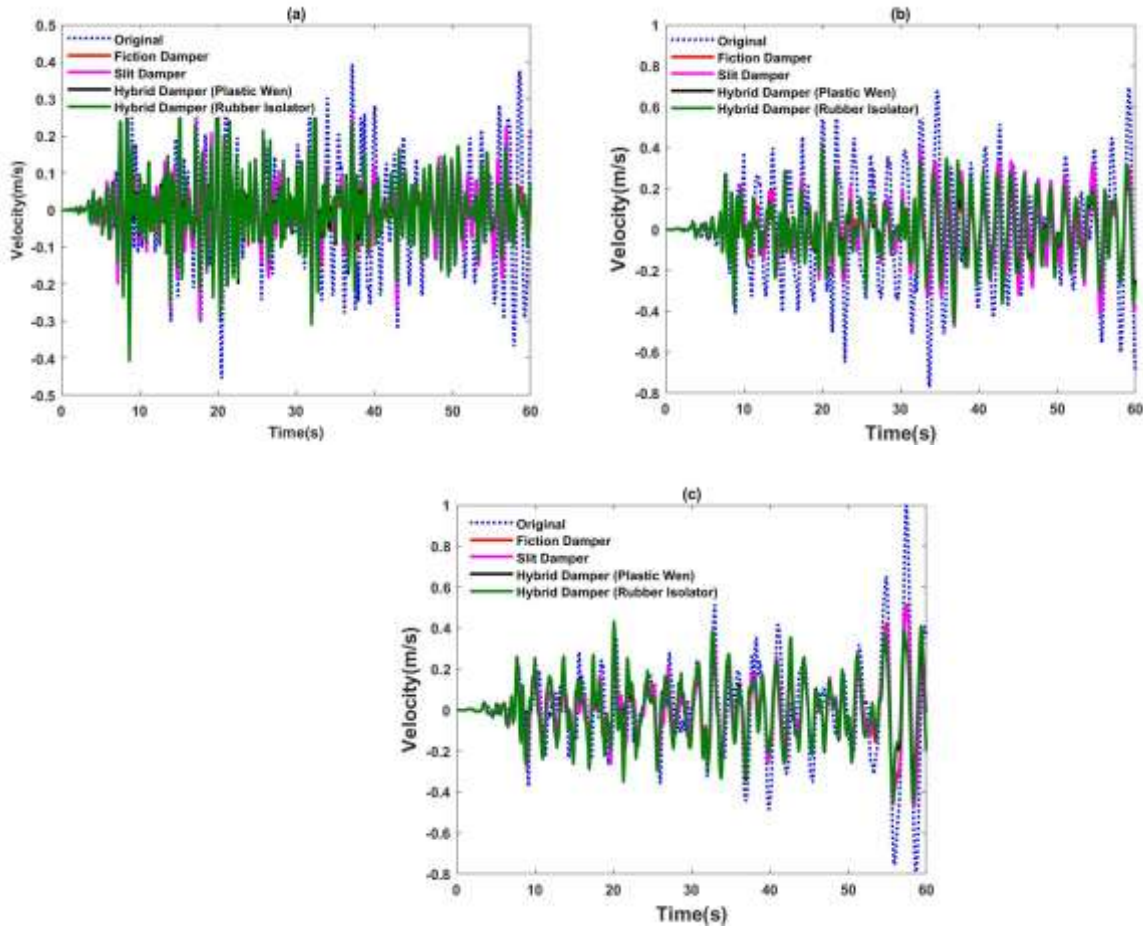


Figure 6. Velocity of the structure: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure

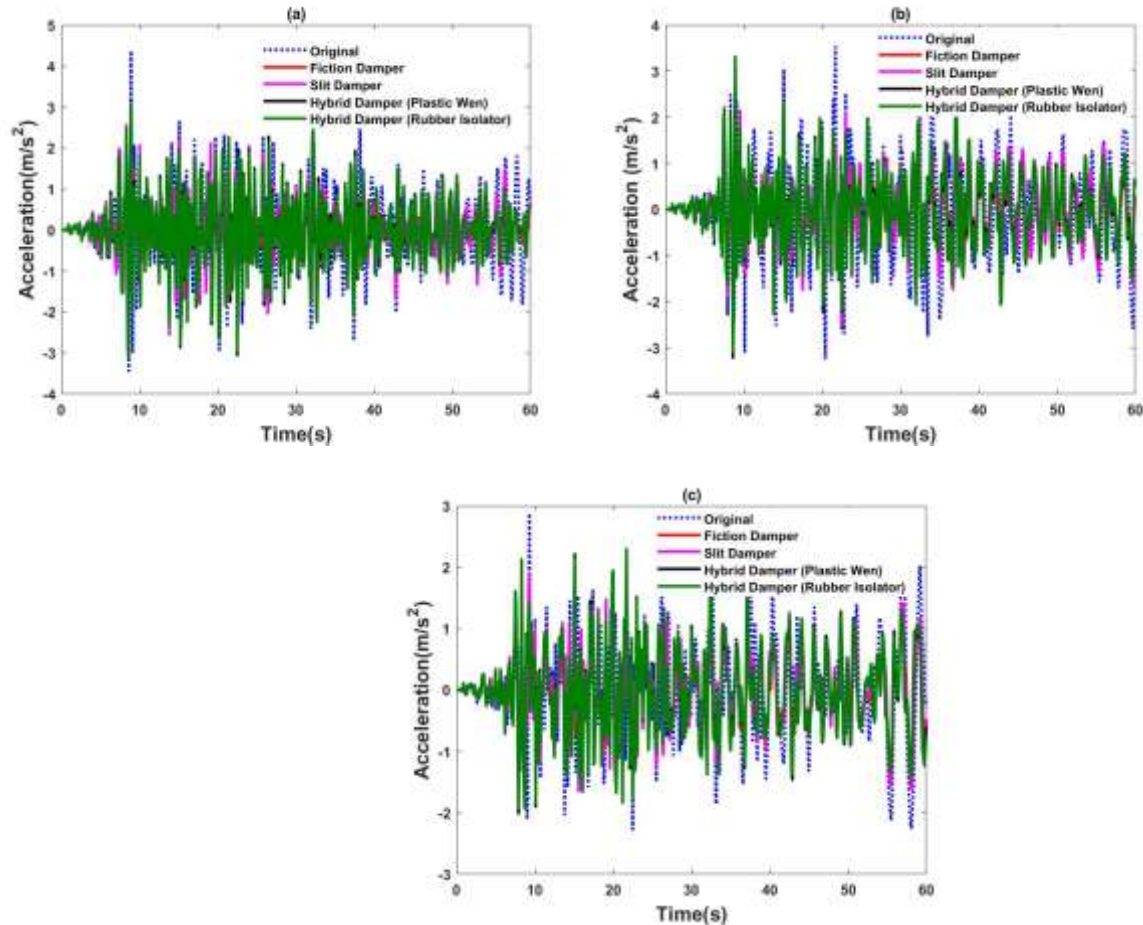


Fig 7. Acceleration of the structure: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure

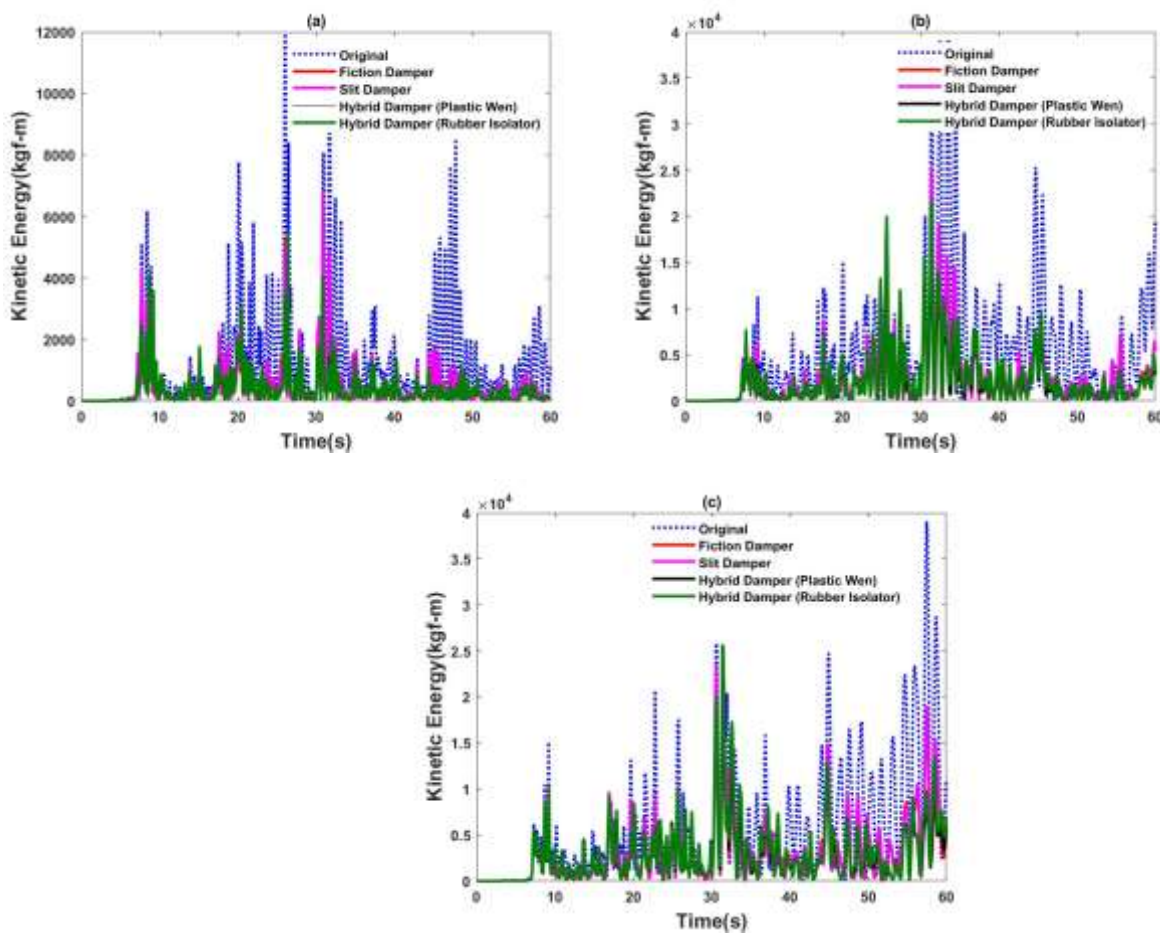


Figure 8. Kinetic energy of the structure: (a) the 5-story structure; (b) the 10-story structure; (c) the 15-story structure

6. CONCLUSION AND DISCUSSION

According to the obtained results, the seismic performance of the structures equipped with damper was better than structures without dampers, so that by placing these dampers in structures according to the pushover analysis, drift and the maximum displacement of the roof were decreased by 33% and 23%, respectively. According to the time history analysis, the displacement of structures by % 60, the velocity of structures also by % 70, the acceleration of structures by 45% and the kinetic energy of the structures by % 51 compared to the original structures. Of course, structures with dampers with Rubber Isolator behavior due to their existence, the effective damping coefficient has a better performance than the dampers modeled with Plastic Wen behavior.

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