EFFECTIVENESS OF DAMPERS IN ENHANCING THE LATERAL LOAD BEARING CAPACITY OF HIGH-RISE STEEL BUILDING

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ABSTRACT

This research paper describes the results of analysis of the seismic behavior of a thirty story steel building with and without damper under different earthquake acceleration signals. The proposed procedure placed the various types of damper like friction damper, bilinear damper and exponential damper on the top three floors of the building. The study compares the different performances such as the joint displacement, joint acceleration, the base force of structure with and without damper for a thirty-story steel building using ETABS 2015. The study further performs time history analysis for different seismic accelerograms to observe the actual time domain responses of the structure. Finally, static pushover analysis in both X and Y direction studies the demand and capacity spectrum. Linear time-history analysis on this steel building structure indicates that maximum joint displacement increases for S-Monica2 seismic accelerogram and decreases for Altadena and Corralit accelerograms; whereas, maximum base force and maximum joint acceleration are effectively reduced for all the seismic accelerograms in the presence of damper at top three floors of the building.

Key Words: — earthquake, damper, static pushover analysis, linear time history, demand and capacity spectrum

1.0 INTRODUCTION

Over the last few decades, the world has experienced numerous devastating earthquakes. As a result, due to the collapse of buildings and severe structural damages in densely populated areas, an increased loss of human life occurred. In developed societies with modern infrastructure, major earthquakes claim significantly fewer lives when compared to prior generations. Our understanding of earthquake mechanisms and seismic ground motions is continually advancing. Furthermore, the understanding of how buildings respond to earthquakes continues to enhance. Recent studies give more importance to the research and development of structural control techniques such as passive control system, active control system, and semi-active control system giving particular importance to the improvement of seismic responses of buildings. Passive control systems do not require any power supply. For the typical design of building against earthquake, resistant of the building stems from the stiffness, ductility, and structural damping, thus, large amounts of energy dissipate through localized damage or plastic hinges formed in the lateral resistant system. Energy dissipation action in a frame system, such as beam and column in a moment-resisting frame produces damage in those components. Repair of such damage after an earthquake is very expensive and often requires evacuation of the building. By locating energy dissipation device to new and existing structures earthquake-induced energy can dissipate efficiently. This enhanced structural system can reduce damage to the structures. Energy-induced by the earthquake can disperse by adding additional equipment called damper. Damper, a device useful as a seismic retrofit or strengthening in new construction, dissipates a significant portion of the induced energy in the most critical parts, so damage to the structure minimizes.

Among the three structural control systems referred in the preceding section, damper system belongs to the passive control group. There are various types of dampers such as a viscous damper, tuned mass damper, friction, bilinear and exponential damper. Among this dampers, exponential, bilinear, friction dampers act as a function of displacement. In Bangladesh, the practice of application of energy dissipation device in existing or new buildings is still at an early stage. This paper intends to focus on the advantages of nonlinear mass damping devices. Nonlinear time history analysis is of paramount importance for seismic analysis and performance study. This research paper presents the nonlinear time history analysis of thirty story steel building frame with and without damper considering S-Monica2, Altadena, Corralit earthquake acceleration signals. The damper proves to be a significant device in enhancing the seismic performance of a building. Current investigation supports the conclusion by proving the contribution of the damper in the reduction of the story displacement, base shear, and joint acceleration while increasing the natural period of the structure.

2.0 METHODOLOGY

The study focuses on the seismic behavior of a 30-story 3D steel frame. Several researchers reported various aspects of damper enhanced structures including linear and nonlinear Static and linear and nonlinear dynamic analysis of buildings frames fitted with dampers. This study locates the damper in top three floors for to enhance its seismic behavior. A comparison of time history analysis with and without damper compares the significant parameters such as story displacements, joint acceleration, and base shear.

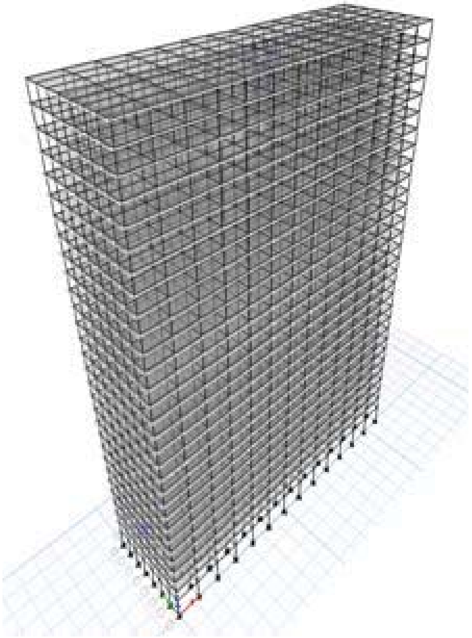

Fig 1: 3d view of model

2.1 Modeling and Assumptions

Structural system analyzed in this paper is a steel frame structure.The building has 13 bay in the X direction and eight bay in Y direction [Figs. 1, 2 and 3], and the height of the building is 305 ft. The damper locates in 30th, 29th, and 28th storey. The current study employs the seismic behavior of the structure assuming that the seismic response is in two perpendicular directions and independent of each other.

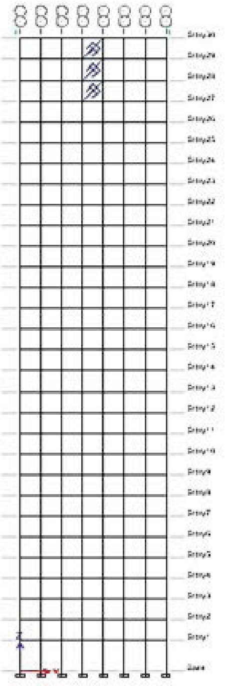

Fig 2: Elevation of model

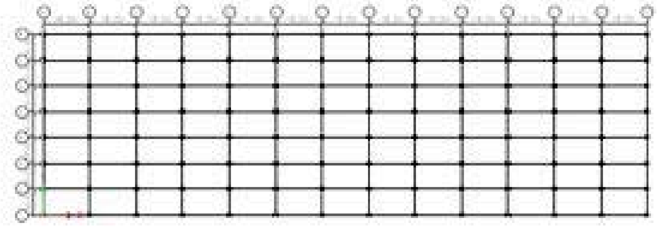

Fig 3: Plan view of model

2.2 Damper Modeling

This study simulates and compares the effect of exponential, bilinear, and friction dampers on the seismic performance of the structure. This paper presents nonlinear time history analysis of the structure using ETABS 2015, a nonlinear FE based structural analysis software.

2.3 Modeling and Specification

Figure 1, 2 and 3 illustrate the 3D, elevation and plan view of 30 story steel frame structure respectively.

Table 1: Damper properties

Properties	Exponential	Bilinear	Friction Spring
Mass (lb-s^2/ft)	73454.1	73454.1	73454.1
Weight (kip)	1301.70	1301.70	1301.70
Effective stiffness (kip/in)	666.5	666.5	666.5
Effective Damping (kip-s/in)	216.82	216.82	216.82
Stiffness (kip/in)	1000	1000	1000
Damping coefficient (kip-s/in)	271.02	-	-
Damping Exponent	1	-	-
Initial Damping coefficient (kip-s/in)	-	1212.056	-
Yielded Damping coefficient (kip-s/in)	-	0	-
Linear Force Limit (kip)	-	0.001	-
Slipping Stiffness(loading) (kip/in)	-	-	1200
Slipping stiffness (unloading) (kip/in)	-	-	1000
Stop displacement (in)	-	-	0

3.0 RESULT AND DISCUSSION

Figures 4 to 7 illustrate the findings from the time history analysis of the 30 story building steel frame structure with mass damper. Table 3 lists the values in the form of the period, moment, and shear value for EQY and WINDY of building frames, base shear or force and base acceleration; story displacement. The investigation observed that there is significant variation in results due to the different earthquake motions.

3.1 Mode Numbers with Period

For modal analysis, the natural period of the building increase with the installation of dampers in the structure. In this regard, exponential dampers work more efficiently, and bilinear damper along with friction spring damper display more or less the same natural period of the building. The reasoning is that as the mass of the building increases, the period also increased according to the following equation

$$T=(2\times\pi\times\sqrt{m})\div(\sqrt{k}) \qquad (1)$$

Here, m= mass of damper
k= stiffness of damper

Table 2 represents the increment of the period for different mode shapes. The increase of building period varies from four to ten percentages.

Table 2: Increment of building period

Modal number	Time period (sec) Without damper	Time period(sec) Exponential damper	Time period (sec) Bilinear damper	Period (sec) Friction damper
1	4.321	4.949	4.949	4.947
2	3.784	3.806	3.806	3.806
3	3.126	3.525	3.525	3.523
4	1.394	1.526	1.526	1.523
5	1.234	1.239	1.239	1.239
6	1.029	1.126	1.126	1.124
7	0.754	0.805	0.805	0.805
8	0.694	0.696	0.696	0.696
9	0.597	0.636	0.636	0.634
10	0.523	0.549	0.549	0.547
11	0.421	0.521	0.521	0.521
12	0.415	0.486	0.486	0.486
13	0.324	0.44	0.44	0.439
14	0.309	0.409	0.409	0.413
15	0.261	0.36	0.36	0.37
16	0.238	0.336	0.336	0.337
17	0.218	0.309	0.309	0.311
18	0.187	0.276	0.276	0.28
19	0.164	0.27	0.27	0.26
20	0.146	0.229	0.229	0.224
21	0.129	0.194	0.194	0.191
22	0.109	0.16	0.16	0.158
23	0.087	0.124	0.124	0.123
24	0.066	0.087	0.087	0.086
25	0.034	0.038	0.038	0.037

3.2 Moment and Shear Value

Moment and base shear value of analyzed building frames increase if dampers locate on the involved frames. Thus, this study only investigates elevation 45GH frames and load cases EQY and WINDY and are shown in figure 4 to 7. Table 3 illuminates the percentages of the maximum increase in shear and moment values of the beams for the 45GH frame performing linear dynamic analysis.

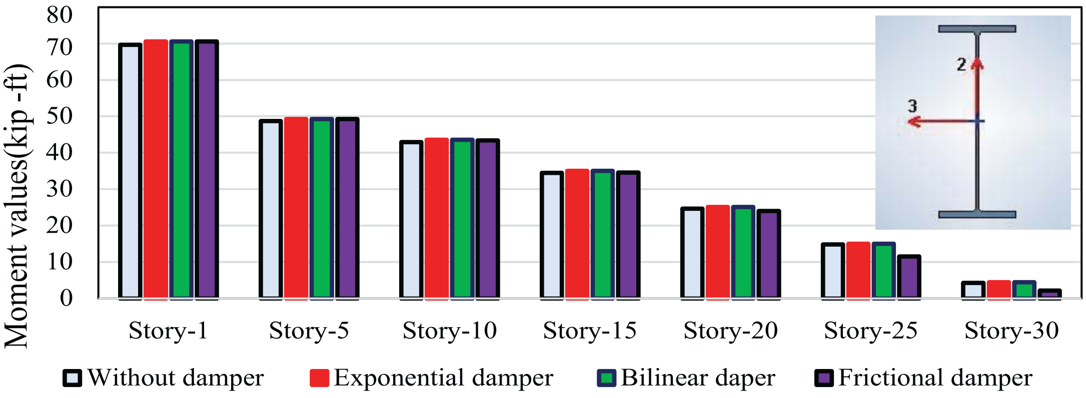

Fig 4: Moment values for WINDY

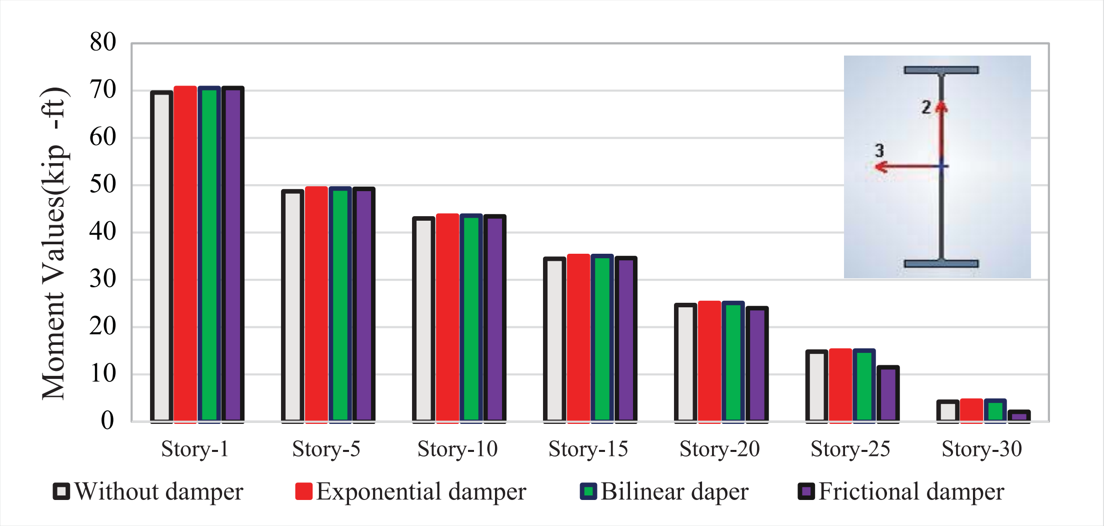

Fig 5: Moment values for EQY

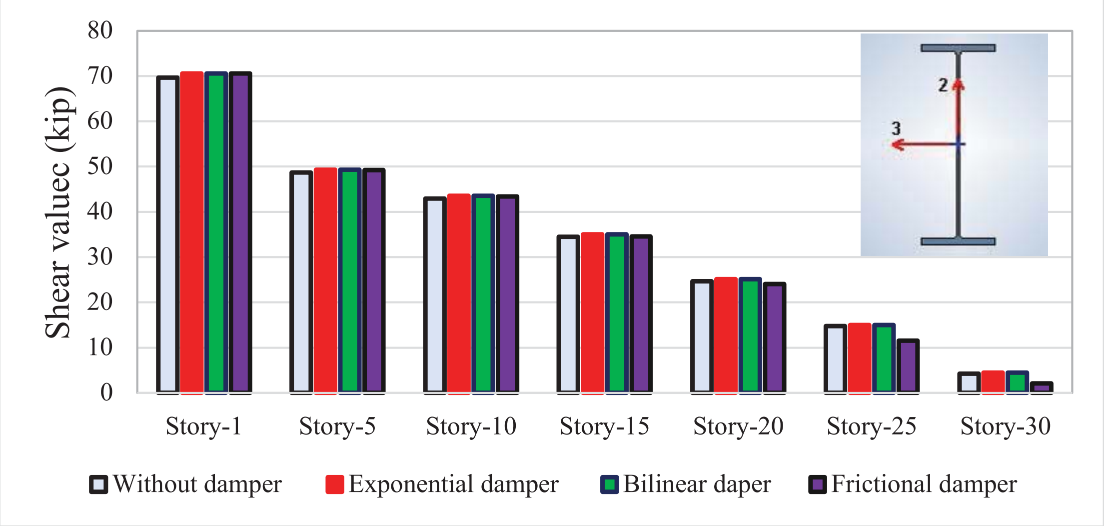

Fig 6: Shear values for EQY

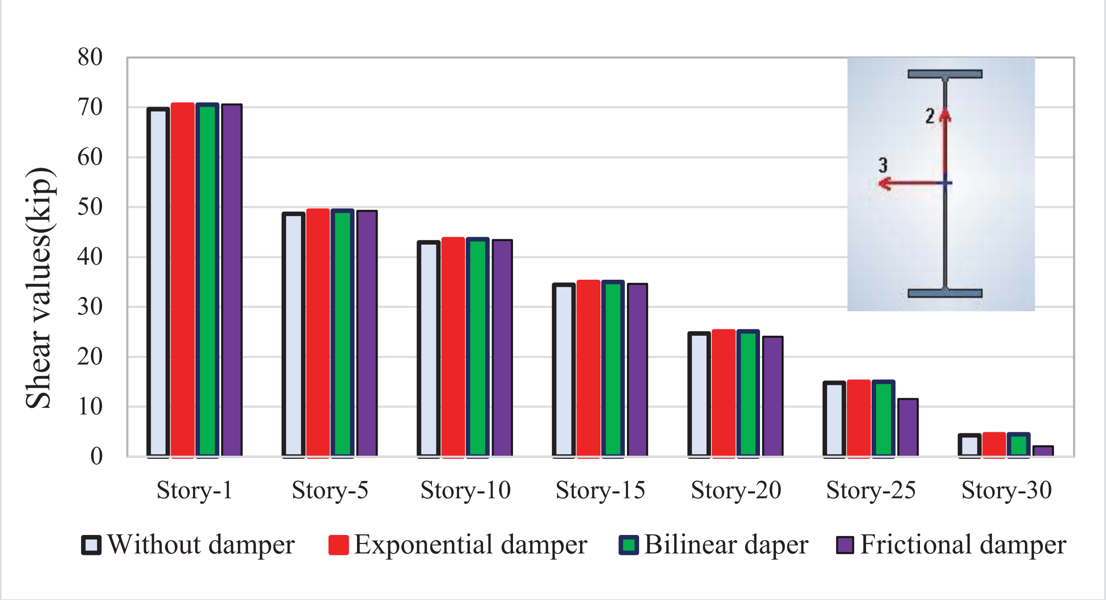

Fig 7: Shear values for WINDY

Table 3: Moment and shear value

Kind of Response	Without Damper	Bilinear Damper	Percent Reduction %	Friction Dampers	Percent Reduction %
Moment (kip-ft) EQY	121.855	140.07	14.95	139.955	14.85
Moment (kip-ft) WINDY	302.531	306.61	1.34	306.513	1.32
Shear (kip) EQY	28.04	32.232	14.95	32.205	14.85
Shear (kip) WINDY	69.61	70.549	1.34	70.568	1.32

3.3 Time History Analysis of Building Frame

ETABS is an FE-based structural design and analysis software. The current research utilizes ETABS 2015 to analyze a thirty-story building frame to study its seismic performance with and without a damper under both linear and nonlinear time history analysis.

3.4 Residual Drift

Residual drift is very threatening for a building as it is the permanent deformations that remain after the earthquake. Installation of dampers at the top portion of the building can successfully reduce the residual drift. Table 4 and figure 8 demonstrate that the residual drift decreases after the installation of the damper, and it becomes almost zero for the exponential damper. Residual drifts of lower levels as well as interstory drift can also be compared if the dampers are installed in the building for different time history analysis like Corralit and Altadena along with S-Monica2. But here only S-Monica2 is shown as drift is maximum at top story of a building for lateral loads and drift reduces for different time history analysis by installing dampers.

Table 4: Residual drift for S_Monica2 at top story

Dampers	Residual Drift*100	Percent Reduction (%)
Without Damper	0.023556	-
Exponential Damper	0.0000856	99.63
Bilinear Damper	0.0002076	99.12
Friction Spring Damper	0.0004079	98.268

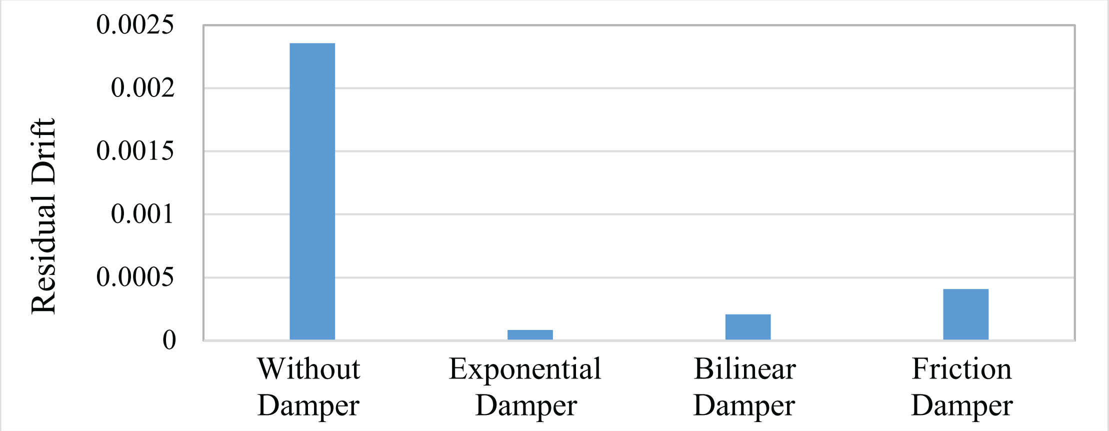

Fig 8: Residual Drift for S_Monica2 at top story

3.5 Maximum Base Shear or Force

Base shear is another important parameter in deriving the response of the frame against earthquake. Base shear decreases with the installation of dampers.

Figure 9 and table 5 illustrate that the base shear forces decrease for all three time history analysis by installing exponential, bilinear and friction spring dampers from the frame having no damper.

Table 5: Base shear for different EQ loads

EQ	WO Damper(kip)	Base Reaction With Damper (Kip)		
		Exponential Damper	Bilinear Damper	Friction Spring Damper
S_Monica2	1565.612	1377.396	1315.1	1376.8
Altadena	3199.046	3063.848	3016.7	3087.70
Corralit	1951.22	1950.22	1897.0	1951.01

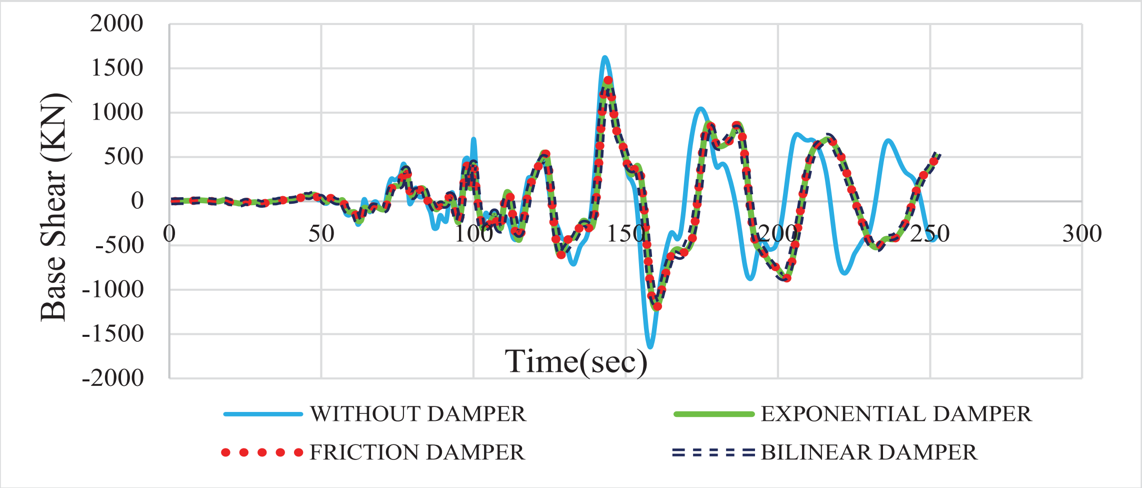

Fig 9: Differences in base shear for S-Monica2 applying different dampers

3.6 Maximum Joint Acceleration

Joint acceleration of 30 story steel frame structure decreases when the damper locates on top three floors for all three-earthquake accelerograms namely, EQ S_Monica2, EQ Altadena, and EQ Corralit load. Table 6 represents the reduction of top floor joint (number 60) acceleration for different earthquake load case when dampers locate in the building compared to the frames without a damper. Joint acceleration reduces more significantly for EQ Altadena. This study extracts from figure 10 table 6 that the installation of mass dampers decreases the joint acceleration for EQ S_Monica2, Altadena and Corralit.

Table 6: Joint acceleration for different EQ loads

EQ	WO Damper (in/sec^2)	Joint Acceleration With Damper (in/sec^2)		
		Exponential Damper	Bilinear Damper	Friction Spring Damper
S_Monica2	164.536	164.235	164.21	164.235
Altadena	502.4486	501.387	501.36	501.981
Corralit	198.267	188.193	177.9	188.034

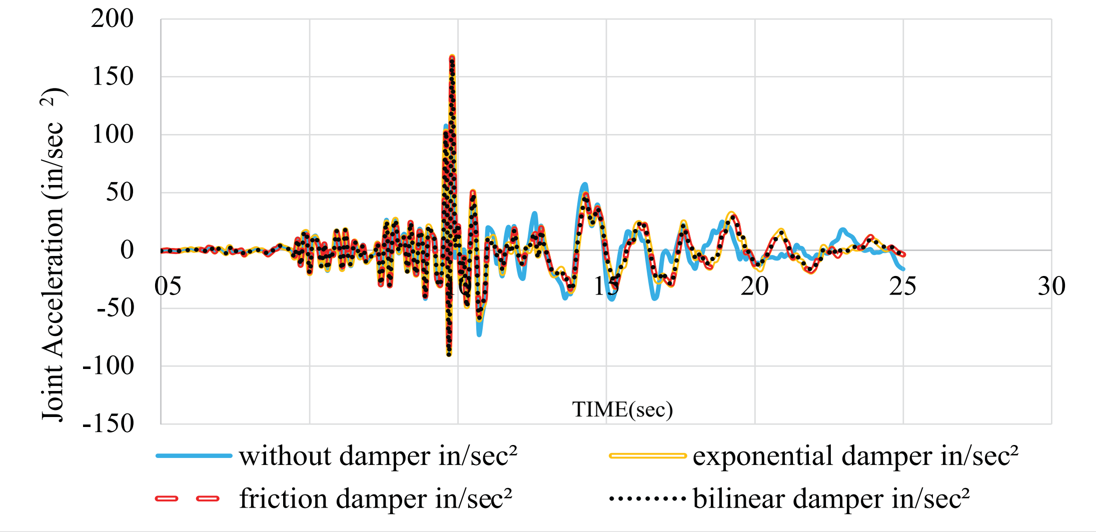

Fig 10: Difference in joint acceleration for S-monica2 applying different dampers

3.7 Maximum Joint Displacement

Table 7 represents that the reduction of top floor joint (number 60) displacement for various earthquake load case when dampers provided in the building compares to the frame without a damper. However, here an interesting result is observed. For EQ S_Monica2, joint displacement is increased but for Altadena and Corralit EQ, joint displacement is decreased. This is because; EQ S_Monica2 has larger amplitude and intensity than the other two earthquakes. Here, figure 11 represents joint displacement only for Corralit EQ. Other time history analysis can also be compared.

3.8 Hysteresis Loop

Energy dissipated by three types of dampers highlights in the graphs provided on the structure. Figure 12 to 14 shows that energy dissipation for bilinear damper is more for steel building than the exponential and friction spring dampers and the displacement indicate the displacement of damper or hysteresis of damper. From figure 14 it is observed that, friction spring dampers are well within the elastic limit showing its linear behavior as its linear diagram shows. Here, only S_Monica2 is analyzed. Other time history analysis for different dampers can also be perceived.

Table 7: Joint displacement for different EQ loads

EQ	WO Damper (in)	Joint Displacement With Damper (in)		
		Exponential Damper	Bilinear Damper	Friction Spring Damper
S_Monica2	5.717643	6.541009	6.4486	6.49356
Altadena	6.468611	5.143085	4.97329	5.10152
Corralit	8.487805	4.699361	4.74011	4.93359

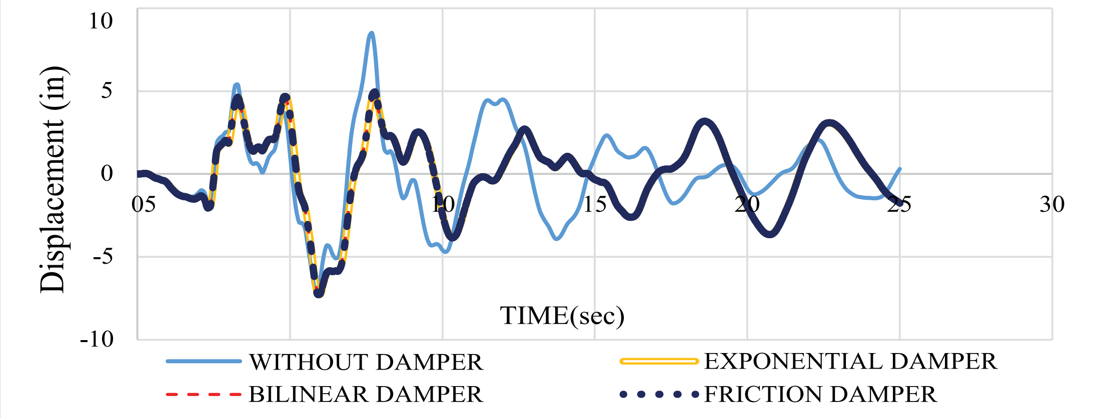

Fig 11: Difference in joint displacement for Corralit applying different dampers

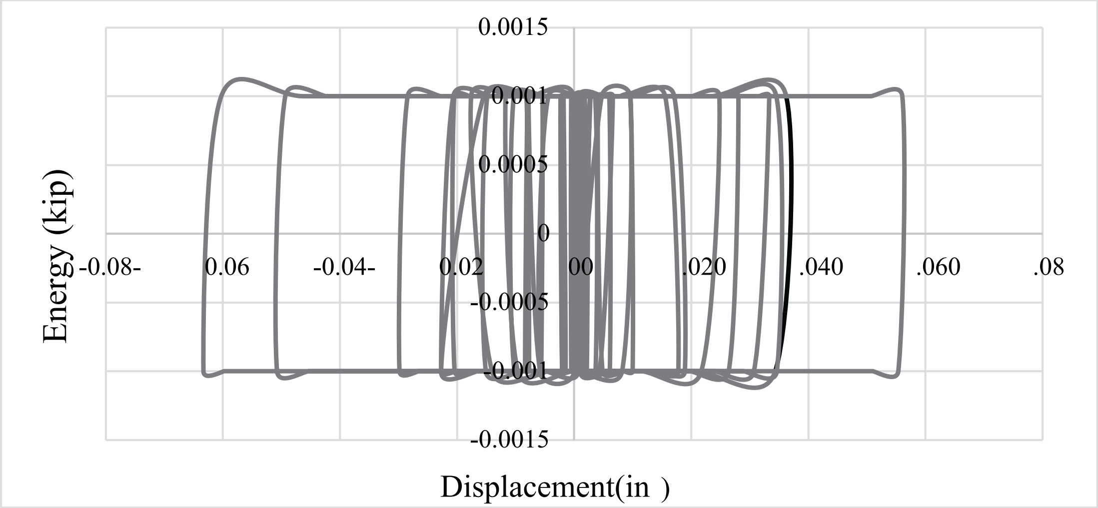

Fig 12: Hysteresis loop for S-Monica2 applying bilinear damper

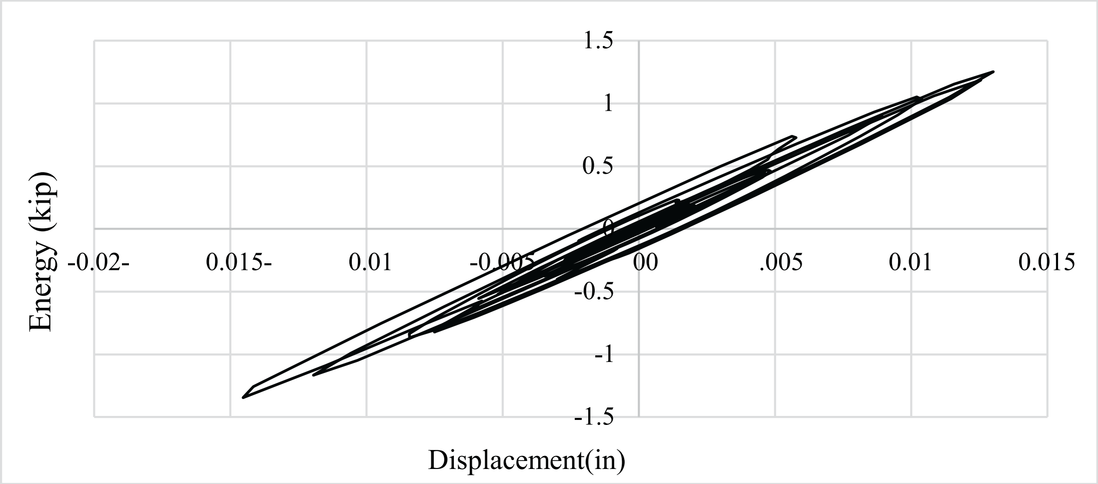

Fig 13: Hysteresis loop for S-Monica2 applying exponential damper

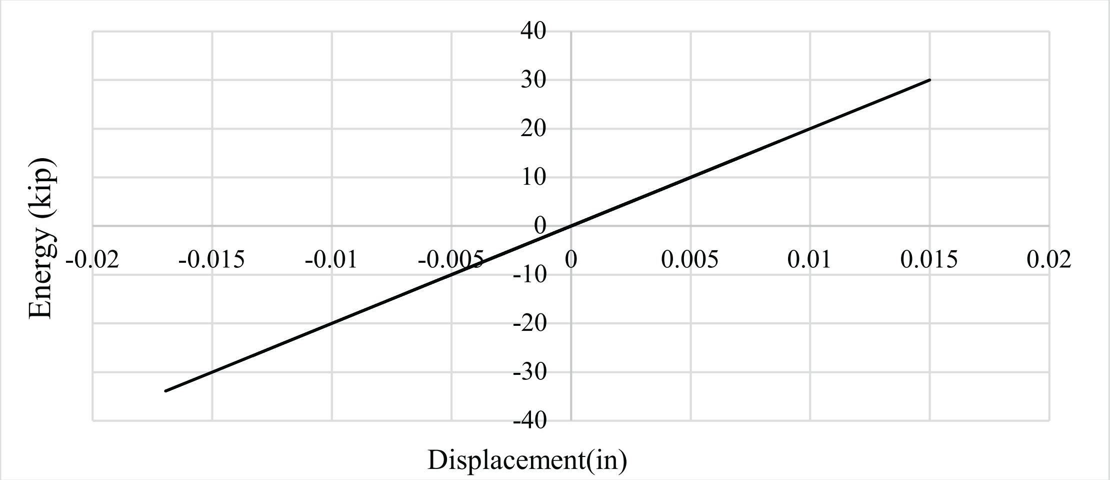

Fig 14: Hysteresis loop for S-Monica2 applying friction spring damper

4.0 CONCLUSION

From the overall discussion and analyses of the study, it can be concluded that:

1. Seismic performance of a building can be improved by installing energy dissipating device (damper) as it absorbs and dissipate energy during an earthquake.
2. Reduction of base shear has been achieved with the deployment of the damper.
3. Reduction of joint acceleration has been achieved with presence of damper, so the inertia forces also reduces.
4. As the story displacement reduces, the structure requires less ductility to resist same earthquake forces. On the other hand, a typical building with limited ductility can withstand larger earthquake loads.
5. Seismic performance can be improved as the modal period increases beyond the typical site period of the structure by installing dampers.

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