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Improving Seismic Performance of Concrete Buildings with Special Moment Frames Using Viscous Damper

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ABSTRACT: The present study attempted to investigate the effect of viscous damper on the performance of 10 and 16-story structures. Data modeling was done based on PERFORM 3D software and energy absorption amount was examined in different modes through viscous dampers. To investigate the effects of the so called dampers on the seismic behavior of the structures, the performance of special moment frames with and without viscous damper with the 20% to 30% Resistance against earthquake damages was considered. Also, hysteresis diagram was studied. The research findings revealed an appropriate effect of viscous dampers on decreasing seismic effects of earthquake such that the structure with damper showed significant energy Dissipation comparing to the structure without damper and the damper with higher damping force plays a more effective role in increasing energy dissipation. Therefore, viscous dampers with higher damping percentage (30%) have a good capability to retrofit structures.

Keywords: Viscous Damper, Special Moment Frame, Concrete Buildings.

I. INTRODUCTION

In seismic retrofitting of structures, using dampers is a method for decreasing the lateral force and increasing the energy loss due to earthquake (Goel 2000; Martinez-Rodrigo et al., 2003). The phenomenon in which the amplitude of vibration is gradually decreased is called damping. In damping, the vibrational kinetic energy of the system is dissipated due to various mechanisms (Mansoori, et al., 2009). Some of the most commonly used dampers include viscous and viscoelastic dampers and frictional and metal dampers (Kasai et al, 2008). With non-similar dynamic characteristics, these dampers show different performances against earthquake input energy (Abbas et al., 1993). As one of the characteristics of viscous dampers, their ability in dissipating earthquake input energy against a wide spectrum of simulation frequencies can be mentioned (Lin et al., 2009). Viscous dampers present a strategy to absorb earthquake energy. In viscous dampers, energy is dissipated by moving viscous liquid inside the cylinder; this liquid is a non-flammable kind of silicon (the oil containing oxygen and quarts). Viscous dampers are highly used in seismic retrofitting due to ease of installation, compatibility with other members, various sizes, high water absorption, and lack of deformation in structure (Sullivan et al., 2000; Whittaker et al., 2010). Moment frames resist the lateral loads by rotating nodes through creating anchor and Shear in the frame member. Furthermore, due to reverse anchors created by the lateral forces, the axial forces are created in the frame`s columns (Pettinga et al., 2005). Moment frames mostly resist against the lateral loads due to nodes' rotation; therefore, displacing or changing the lateral position of such frames is significant against strong earthquakes (Fazilati & Mostofi Nejad, 2001). During the recent years, many efforts have been done to develop the concept of passive energy dissipation or additional damping and a lot of these equipment have been installed on structures all around the world (Soong et al., 1997). Although it is very difficult to fully avoid the resulted damages due to strong earthquakes, losses and damages due to the future earthquakes can be decreased to a great extent by increasing the security level of structure and the percentage of the wasted energy through proper retrofitting and immunizing. The present paper tends to investigate the seismic behavior of reinforced concrete special moment frames with viscous dampers under different earthquake effects. Viscous dampers can be used in seismic retrofitting of reinforced concrete special moment frames which are vulnerable against earthquake as well as in enhancing their seismic performance. To study the effects of these dampers in structures` seismic behavior, the performance of special moment frames with and without considering damper against earthquake was investigated.

II. METHODOLOGY

In the present study, two 10-story and 16-story concrete buildings with special moment frame have been selected to investigate the effects of viscous damper.

In order to design the primary model of the structures, ETABS version 4, 7, and 9 have been used. The primary model has been designed using equivalent statistical analysis. In model design, the Roof of the structure has been supposed as a rigid diaphragm and columns' bases have also been considered to be rigid. The sub-foundation soil has been considered as type 2 and the design has been performed based on ACI-318-99 provisions. The lateral loading of the model has been done based on 2800 provisions of Iran. Earthquake coefficient C has been computed using equation $\frac{ABI}{R}$. The gravity loading has been performed based on the sixth discussion of the National Building Principles for residential buildings; therefore, dead load and live load have been applied to the roof of 650 kg/m^2 and of 200 kg/m^2, respectively.

Table 1. The Computation Results of Earthquake Coefficient for 10-story and 16-story Structures with Reinforced Concrete Moment Frame

Special Moment Frame										
Structure	A (g)	I	R	H (m)	T	T_0	T_S	S	B	C
10-story	0.35	1.4	10	30	0.9	0.1	0.5	1.5	1.69	0.083
16-story	0.35	1.4	10	48	1.28	0.1	0.5	1.5	1.34	0.066

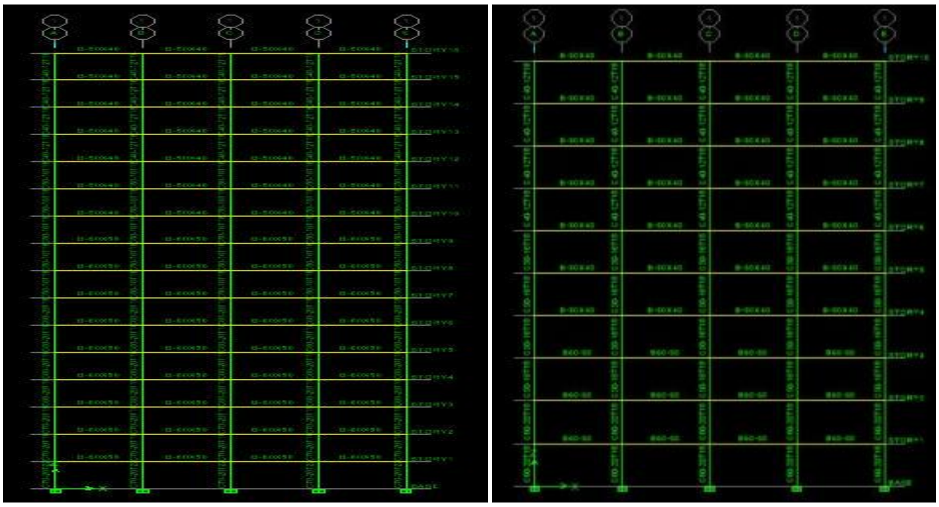


Figure 1. A 10-story Building Frame (a), A 16-story Building Frame (b)

The frame of the 10-story building included Box columns of 60×60mm, 50× 50mm, and 40×40mm and the beams of 60×50mm and 50×40mm. The frame of the 16-story building included Box columns of 70×70, 60×60, 50×50, and 40×40 and the beams of 60×50 and 50×40. The column-foundation joint has been supposed rigid.

Modeling and non-linear analyses of the buildings were performed using PERFORM-3D software. Accelerograms which are used to determine the effect of the ground`s motion should indicate real movement of the ground at the construction site during earthquake as much as possible. To achieve this result, two accelerograms belonging to various horizontal components of earthquake were selected which had the following characteristics:The accelerograms belong to earthquakes which satisfy the design's earthquake conditions and the distance from fault has been considered as large effects in them. The sites of the accelerograms are similar to the building sites due to geological, tectonic, seismic, and specially the soil layers' characteristics. In the accelerograms, the Period of the ground`s strong motion at least equals to 10 seconds or three times of the main period of the structure. In PERFORM software, viscous dampers have been modeled as the diagonal bracing elements in the side spans. To determine the capacity of the applied dampers, the amount of the total lateral damping capacity is needed to be determined for the models. For this purpose, 20% and 30% damping have been considered for the total damping of the structure. Considering the supposition of 5% inherent damping for the structure, the total capacity of the dampers are determined such that the amount of the lateral damping percentage due to the dampers are 15% and 25% to analyze the considered frame. The damping coefficient value of the buildings has been computed as follow:

$$\varepsilon_{c-x} = \frac{C_X}{2mw_x} \rightarrow c_x = \frac{4 * \pi w}{T_x} \frac{}{g} \varepsilon_{c-x} \qquad (1)$$

III. RESULTS

As shown in Table 2, the periods obtained from the software and the periods obtained from ETABS software for each building have been compared to evaluate the accuracy of the modeling in PERFORM-3D.

Table 2. The Comparison of the Periods Obtained from PERFORM-3D with the Periods Obtained from ETABS

Structural System	**Number of Stories**	**Time Period in ETABS**	**Time Period in PERFORM**
Special Moment Frame	10	0.87	0.91
Special Moment Frame	16	1.25	1.3

Table 3. Seismic Characteristics of the Near Selected Area

Earthquake	Year	Station	Direction	Ground Velocity Background	Soil Type	Total Time Duration (sec)
Tabas	1978	9101	H1	0.836	II	32.84
			H2	0.852		
Imperial Valley	1979	Bonds Corner	H1	0.588	II	37.61
			H2	0.775		
Cape Mendocino	1992	89156 Petrolia	H1	0.59	II	36

Source: WWW.peer.berkeley.edu

Accelerograms have been scaled 0.7g.

Table 4. The Characteristics of Damping Coefficient of Viscous Damper

ξ = 20%						
Structural System	Number of Stories	T	W	θ	C_x	C_{ori}
		Period	Structure Weight	Damper`s angel with Horizon	Damping Coefficient of Viscous Damper	Damping Coefficient of Viscous Damper in Diagonal Mode
		Second	Kilogram Force	Radian	Kilogram Force s/m	Kilogram Force s/m
Special Moment Frame	10-story	0.91	523226	30.96	143214.7059	194772
Special Moment Frame	16-story	1.3	891357	30.96	174437.5639	237235

ξ = 30%						
Structural System	Number of Stories	T	W	θ	C_x	C_{ori}
		Structure Period	Structure Weight	Damper`s Angle with Horizon	Damping Coefficient of Viscous Damper	Damping Coefficient of Viscous Damper in Diagonal Mode
		Second	Kilogram Force	Radian	Kilogram Force s/m	Kilogram Force s/m
Special Moment Frame	10-story	0.91	523226	30.96	214822.0589	292158.0001
Special Moment Frame	16-story	1.3	891357	30.96	261656.3458	355852.6303

In the following figures, the positions of the viscous dampers in the building have been shown.

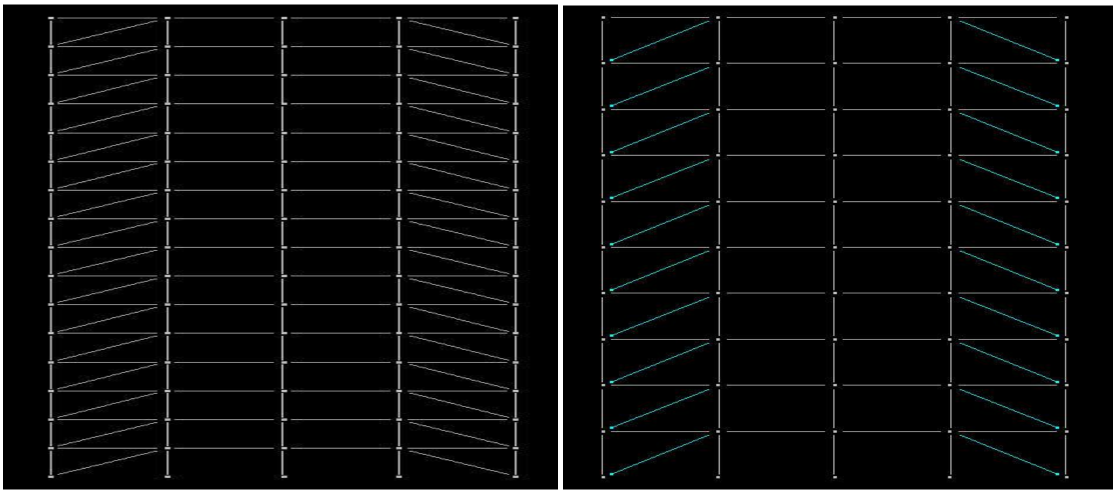


Figure 2. The Places of Viscous Dampers in (a) a 10-story Building and (b) a 16-story Building

Investigation of the Results in the Buildings with Damper and without Damper

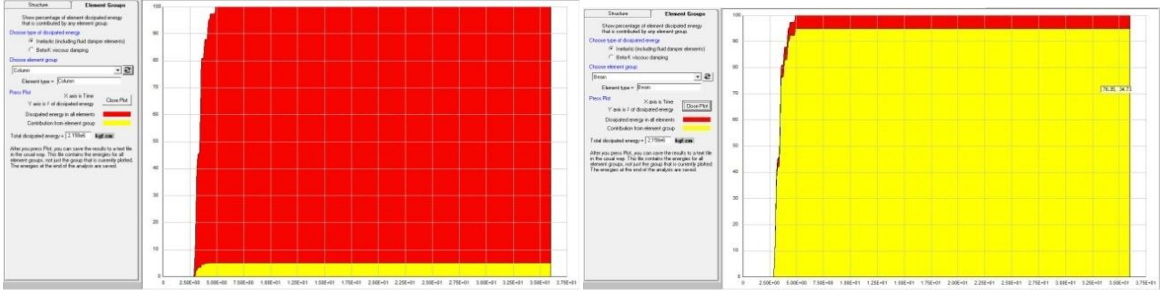


Figure 3. The Energy Loss Percentage in a 10-story Building without Dampers in (a) Beams and (b) Columns under Tabas Earthquake

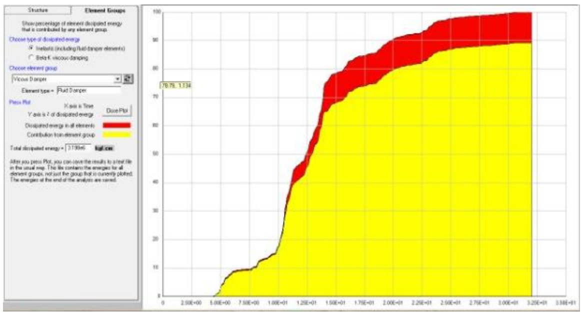


Figure 4. Energy Loss Percentage in a 10-story Building with Viscous Damper of 20% Damping Power under Tabas Earthquake

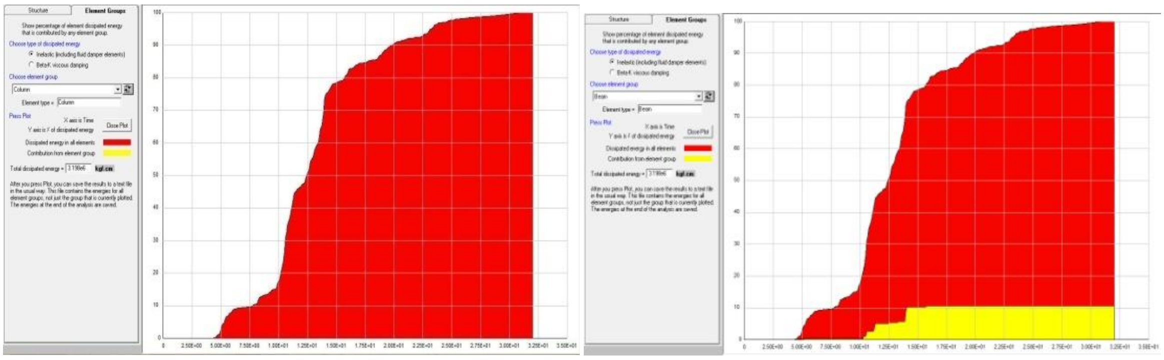


Figure 5. Energy Loss Percentage in (a) Beams and (b) Columns of a 10-story Building with Viscous Damper of 20% Damping Power under Tabas Earthquake

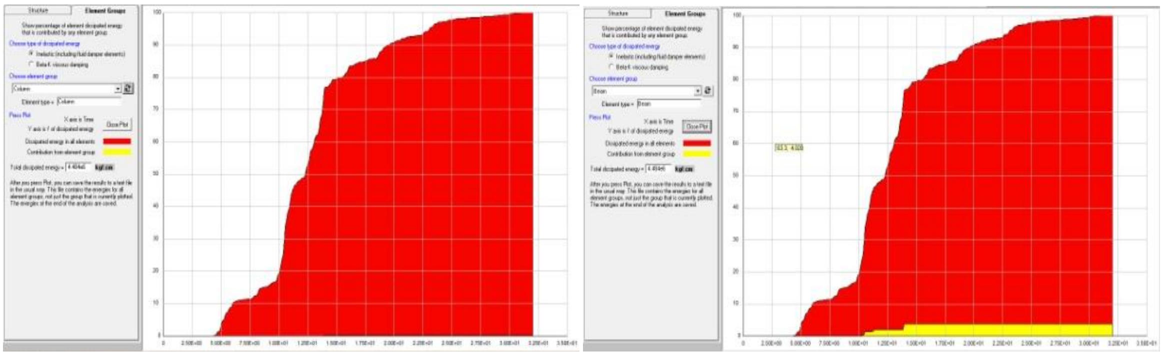


Figure 6. Energy Loss Percentage in (a) Beams and (b) Columns of a 10-story Building with Viscous Damper of 30% Damping Power under Tabas Earthquake

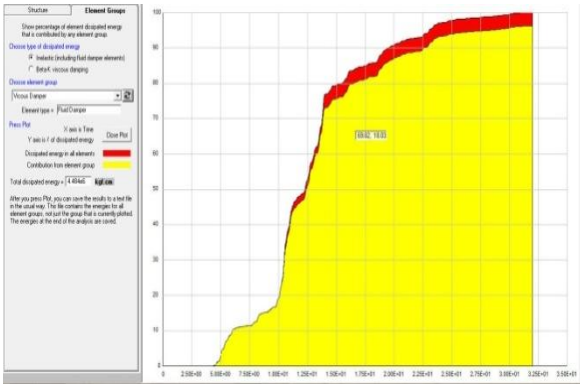


Figure 7. Energy Loss Percentage in Viscous Dampers of a 10-story Building under Tabas Earthquake

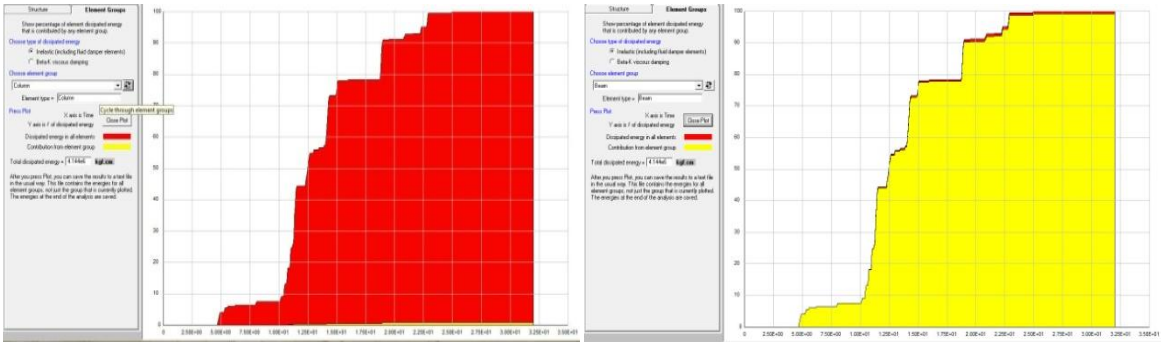


Figure 8. Energy Loss Percentage in (a) Beams and (b) columns of a 16-story Building without Viscous Damper under Tabas Earthquake

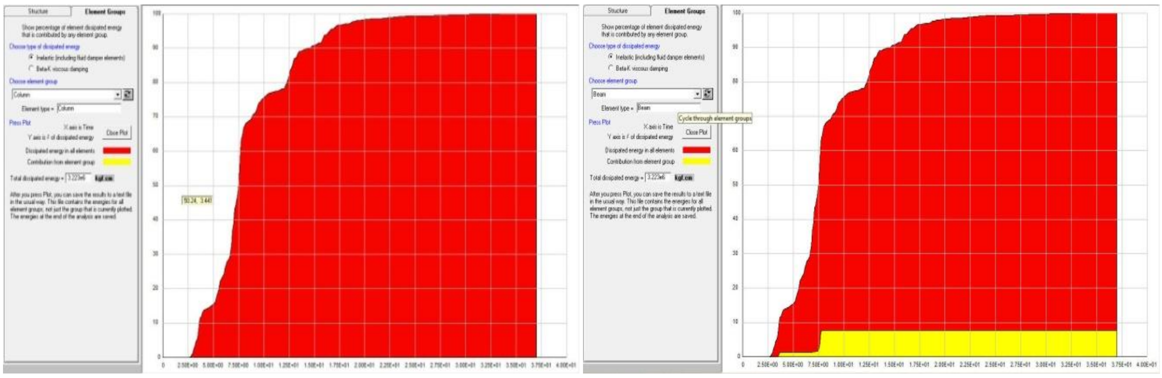
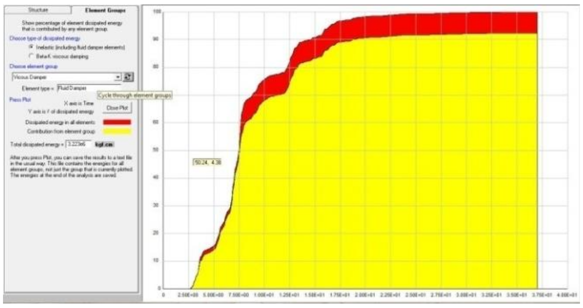


Figure 9. Energy Loss Percentage in (a) Beams and (b) Columns of a 16-story Building with Viscous Damper of 20% Damping Power under Tabas Earthquake



Structure | Element Groups

Show percentage of element dissipated energy that is contributed by any element group.

Choose type of dissipated energy

● Inelastic (including fluid damper elements)

○ Beta-K viscous damping

Choose element group

Viscous Damper

Element type = Fluid Damper

Press Plot

X axis is Time

Y axis is % of dissipated energy

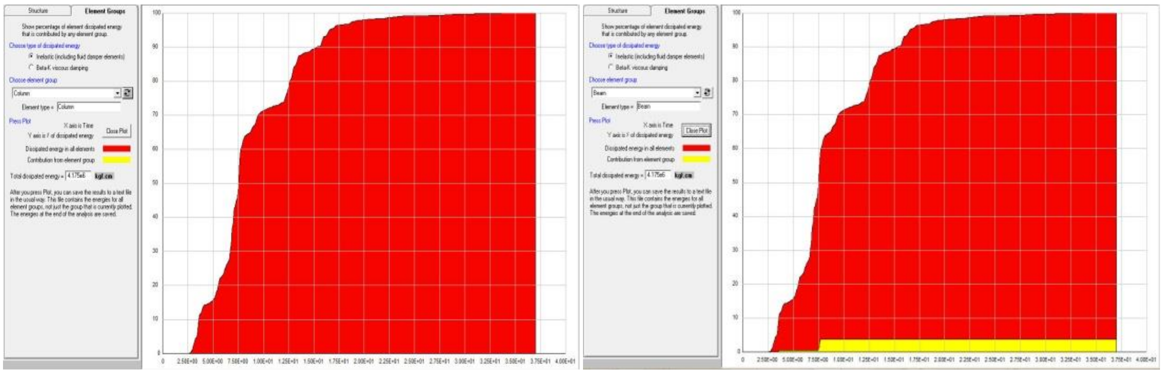
Dissipated energy in all elements 🟥

Contribution from element group 🟨

Total dissipated energy = 3.223e6 kgf.cm

After you press Plot, you can save the results to a text file in the usual way. This file contains the energies for all element groups, not just the group that is currently plotted. The energies at the end of the analysis are saved.

Figure 10. Energy Loss Percentage in Viscous Dampers of a 16-story Building under Tabas Earthquake



Structure | Element Groups

Show percentage of element dissipated energy that is contributed by any element group.

Choose type of dissipated energy

● Inelastic (including fluid damper elements)

○ Beta-K viscous damping

Choose element group

Column

Element type = Column

Press Plot

X axis is Time

Y axis is % of dissipated energy

Dissipated energy in all elements 🟥

Contribution from element group 🟨

Total dissipated energy = 4.175e6 kgf.cm

After you press Plot, you can save the results to a text file in the usual way. This file contains the energies for all element groups, not just the group that is currently plotted. The energies at the end of the analysis are saved.

Structure | Element Groups

Show percentage of element dissipated energy that is contributed by any element group.

Choose type of dissipated energy

● Inelastic (including fluid damper elements)

○ Beta-K viscous damping

Choose element group

Beam

Element type = Beam

Press Plot

X axis is Time

Y axis is % of dissipated energy

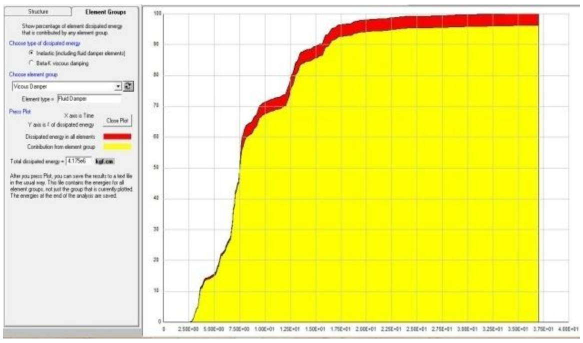
Dissipated energy in all elements 🟥

Contribution from element group 🟨

Total dissipated energy = 4.175e6 kgf.cm

After you press Plot, you can save the results to a text file in the usual way. This file contains the energies for all element groups, not just the group that is currently plotted. The energies at the end of the analysis are saved.

Figure 11. Energy Loss Percentage in (a) Beams and (b) Columns of a 16-story Building with Viscous Damper of 30% Damping Power under Tabas Earthquake



Structure | Element Groups

Show percentage of element dissipated energy that is contributed by any element group.

Choose type of dissipated energy

● Inelastic (including fluid damper elements)

○ Beta-K viscous damping

Choose element group

Viscous Damper

Element type = Fluid Damper

Press Plot

X axis is Time

Y axis is % of dissipated energy

Dissipated energy in all elements 🟥

Contribution from element group 🟨

Total dissipated energy = 4.175e6 kgf.cm

After you press Plot, you can save the results to a text file in the usual way. This file contains the energies for all element groups, not just the group that is currently plotted. The energies at the end of the analysis are saved.

Figure 12. Energy Loss Percentage in Viscous Dampers of a 16-story Building under Tabas Earthquake

According to the obtained results, the highest percentage of energy loss is attributed to the damper. As shown in Figures 3-11, there is no energy loss in the building`s columns; this results in the increase of the structure efficiency.

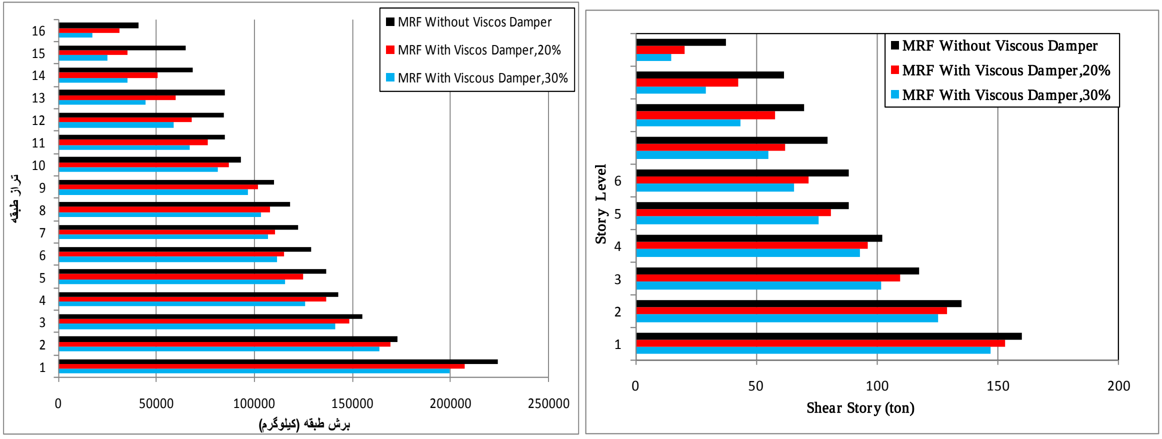


Figure 13. The Comparison of shear of (a) a 10-story Building`s Base and (b) a 16-story Building’s Base with Viscous Dampers of 20% and 30% Damping Power and without Damper under Cape Mendocino Earthquake

Investigation of the Story Drift in Buildings

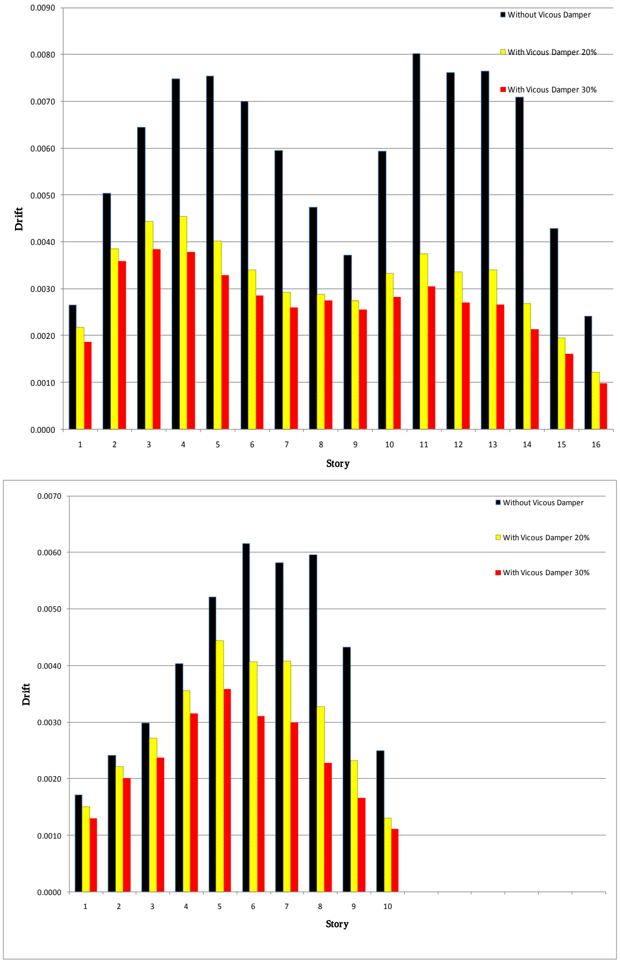


Figure 14. The Comparison of the Drift between the Stories of (a) a 10-story Building with Viscous Dampers of 20% and 30% Damping Power and without Damper under Imperial Vally Earthquake; (b) The Comparison of the Drift between the Stories of a16-story Building with Viscous Damper of 20% and 30% Damping Power and without Damper under Tabas Earthquake

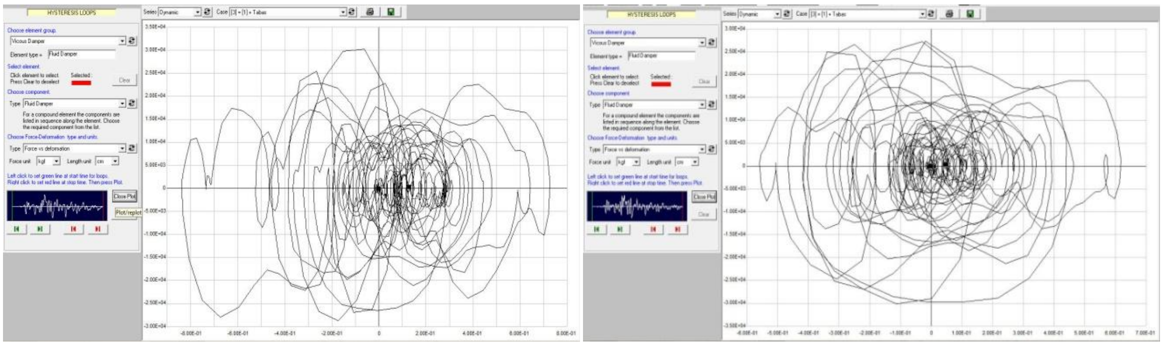


Figure 15. The Hysteresis Curve of Viscous Damper in (a) a 10-story Building and (b) a 16-story Building under Tabas Earthquake

As shown in Figure 15, the hysteresis curve of viscous damper is oval-like and the diagram`s lower surface is relatively high indicating that this fact plays a significant role in increasing the effect of damper in the energy loss.

PUSH OVER Curve and the Computation of the Target Place in 10-story and 16-story Buildings with and without Viscous Damper

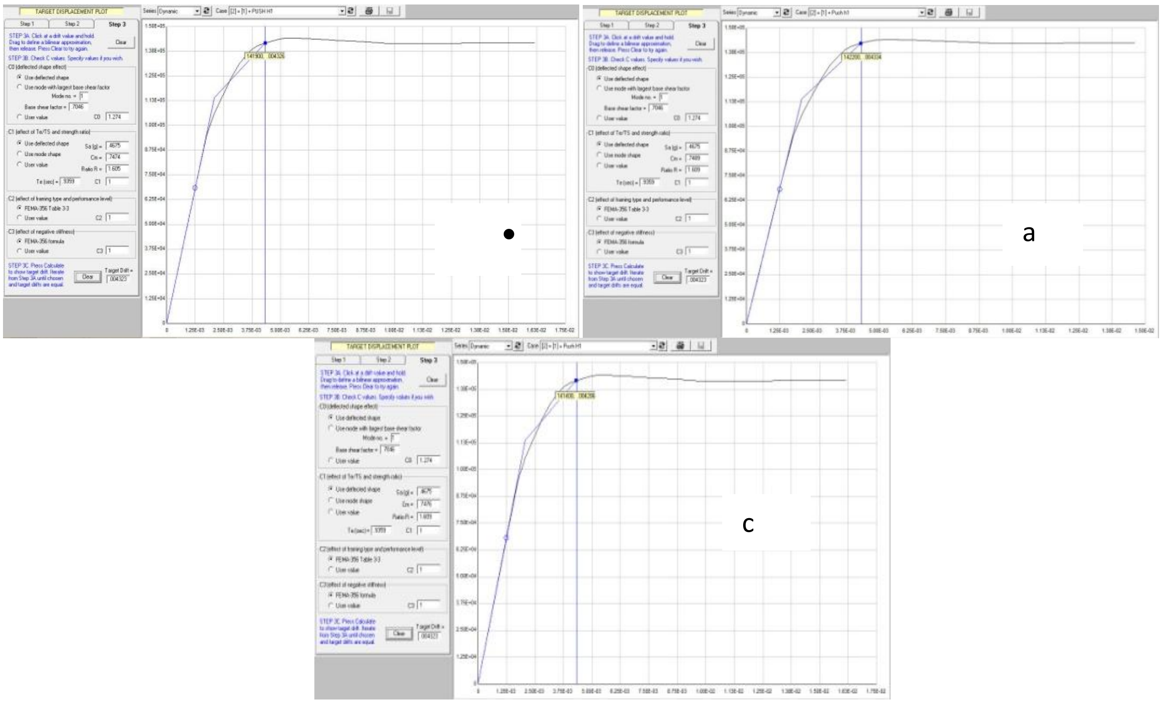


Figure 16. The Curve of Base Cut versus Ceiling Drift in Comparison with the Ground in a 10-story Building (a) without Viscous Damper; (b) with Viscous Damper of 20% damping Power and (c) with Viscous Damper of 30% Damping Power

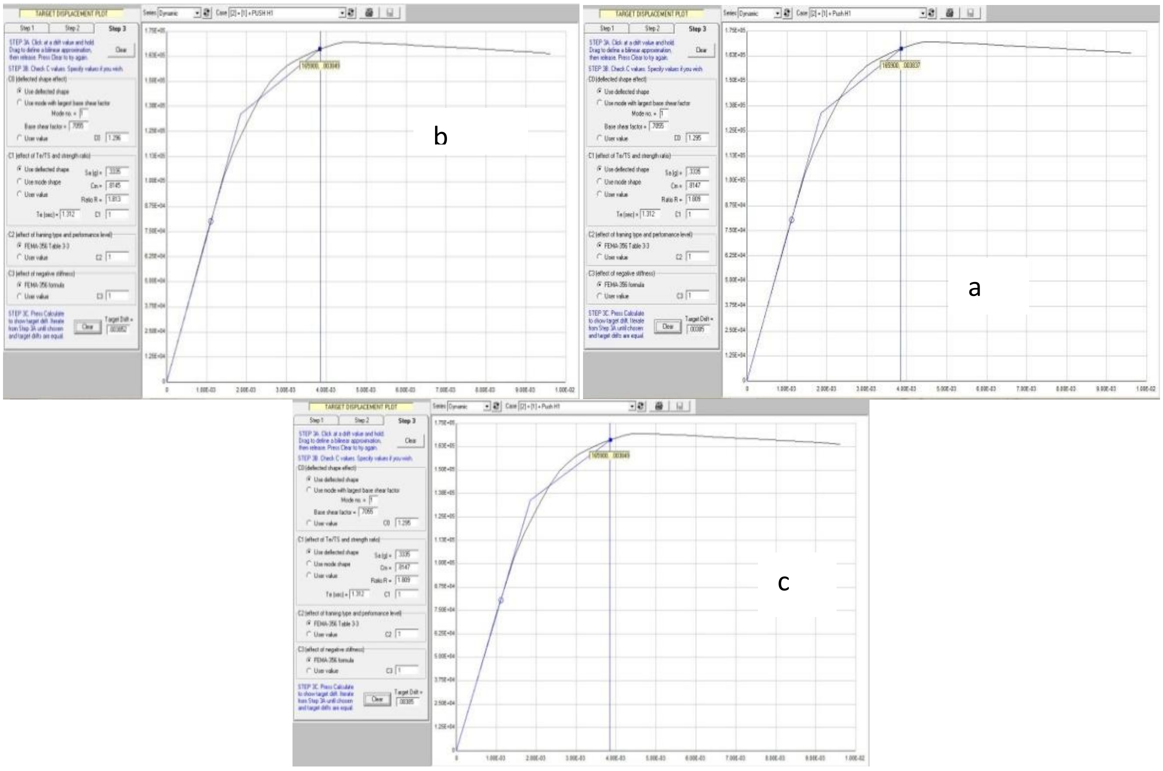


Figure 17. The Curve of Base shear versus roof Drift in Comparison with the Ground in a 16-story Building (a) without Viscous Damper; (b) with Viscous Damper of 20% Damping Power and (c) with Viscous Damper of 30% Damping Power

According to the obtained results, viscous damper in building results in the decrease of building drift and base shear. Besides, damping power in viscous damper is increased from 20% to 30%. As observed in the Figures, building drift and base shear are decreased due to the increase of damping power of viscous damper. Furthermore, viscous damper of 30% damping power restrains 97% of earthquake energy under Tabas earthquake, while viscous damper of 30% damping power restrains about 86% of the earthquake input energy; this indicates that increasing damping power in viscous dampers results in the enhancement of buildings efficiency and the improvement of their performance during earthquake.

IV. DISCUSSION

As the research findings revealed, viscous dampers are considered as highly efficient tools in absorbing earthquake energy. As observed, these tools play a significant role in decreasing and controlling maximum drift of structure. As the findings obtained by Goel and Booker (2001) showed, dampers affect drift, ductility, and dissipation of hysteretic energy in the structures with dampers (Goel & Booker, 2001). Other studies also confirm the capability of the viscous damper in this regard (Link et al., 2009). According to the findings obtained by the present study, damper with 30% damping power restrains 97% of earthquake effects indicating the affective role of viscous damper in destructive effects due to earthquake.

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