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Seismic Performance of Reinforced Concrete Frame Building with Fluid Viscous Damper

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Abstract
The recent influx of high magnitude earthquakes over the past few years create a scope of study in the field of seismic protection and its value in safeguarding the structures like buildings and bridges. Conventional practices like addition of shear wall and bracing systems add stiffness and strength to structure. But, as we add stiffness to the structure this decreases the period hence increasing the acceleration and demand to the structure. In alternative, there can be a method to reduce the dynamic responses and demand base shear by adding supplementary damping to the structure. In order to adequately protect against seismic activity, energy dissipation devices such as fluid viscous dampers (FVDs) are often applied to mitigate structural sway in structures. The prime objective of this paper is to study the effect of damper parameters for the design of nonlinear FVD on Reinforced concrete framed structure to enhance the seismic performance. A general finite element package of ETABS has been used to generate three dimensional model of four storey reinforced concrete building to undertake non-linear Time History analysis to capture the performance of building with and without damper for different damper parameters and different damper distribution. The main responses of comparison between structures modeled with different viscous damper parameters are story displacement, story drift, and Base shear. After analysis the results showed that installing non-linear FVD with appropriate parameters reduces the responses of structure during seismic event. The lower the velocity exponent the more efficient the viscous damping for seismic energy dissipation. Diagonal corner damper distribution is more effective than mid chevron (double diagonal) distribution of presented RC structure.

Keywords
Reinforced concrete structure, Fluid viscous damper, damping coefficient, velocity exponent, Time History Analysis

1. Introduction

An earthquake pumps an energy into a structure. It is not safe for structure to absorb vibration so we want an external device to be installed which will dissipate the energy much like an automobile brake. In order to adequately protect against seismic activity, energy dissipation devices such as fluid viscous dampers (FVDs) are often applied to mitigate structural sway in structures.It is velocity activated device which absorbs kinetic energy and can be used to protect structures by reducing dynamic amplification of motion caused by hazardous vibrations. It enhances seismic performance by decreasing drifts and inelastic deformation demands on the structure.

There is a piston head assembly and orifices and basically with a movement of the piston which is driven by the relative deformation of structural points through which the dampers is connected displaces incompressible silicone fluid one chamber to another. It generates damping force to reduce amplitude of vibration. Diversity in their size, easy installation and coordination with other members make fluid viscous damper demanding in the field of designing and

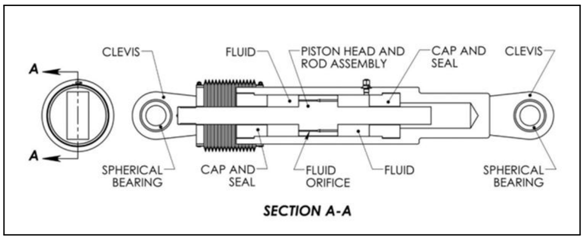

Figure 1: Typical Fluid Damper and Parts. Courtesy: Taylor devices Inc.

retrofitting. The section of fluid viscous damper is shown in figure 1.

The behavior of a fluid viscous damper is idealized as a pure dashpot as shown in the equation below:

Damping Force (F) = C *V $^{\alpha}$.......... (Eq. 1)

The above equation provides relationship between output force and velocity, where C and alpha are the damping constant and velocity exponent, respectively. An alpha of 1.0 represents linear dampers, whereas value other than 1.0 indicate nonlinear dampers. Several studies have shown that selecting the affordable damping parameters of fluid viscous damper reduces the seismic response effectively.

This paper presents the analysis of reinforced concrete structure under a variety of damper parameters for the design of nonlinear Fluid Viscous damper to enhance seismic performance of the structures. Firstly, the mathematical modelling of fluid viscous damper parameters is presented. Then, a numerical analysis of Four-story RC framed structure with different parameters of dampers is carried out in next section. Later, the results of analyses are explained, and a discussion is presented. Finally, results are shown that by installing nonlinear FVD with affordable parameters the seismic response can be decreased significantly.

2. Objective

The main objective of this study is to determine and compare the seismic response of RC frame building with change in damper parameters for the design of nonlinear FVD.

The damping parameters include damping coefficient and velocity Exponent and the main responses for comparison between structures modeled with different viscous damper parameters are story displacement, story drift and Base shear.

3. Methodology

A Four story RC framed structure is used for the present study. The architectural plan and Finite Element model of structure are been shown in figure 2 and 3.

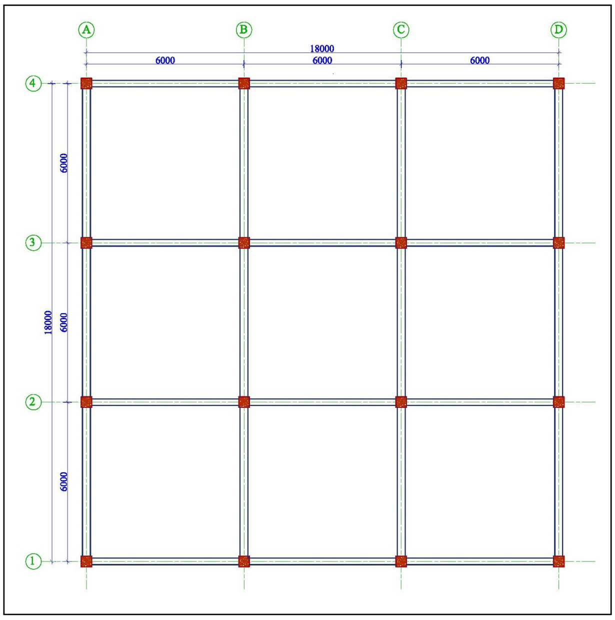

Figure 2: Plan of RC framed Structure

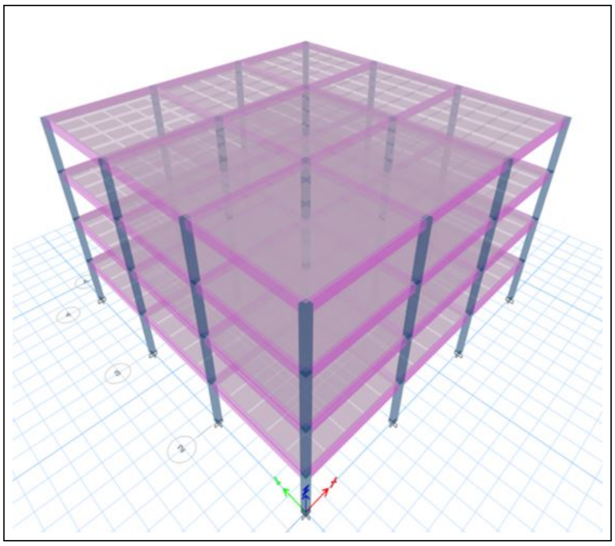

Figure 3: Finite Element Model of RC framed structure

3.1 Assumptions and Description of Frame Structure

The building configuration and structural details are limited as stated.

- Only bare frame is taken for the analysis process. The stiffness due to the infill wall is neglected.
- Height of Each Floor: 3 m
- Total Height of building: 12 m
- Live Load: 4.0 KN/m2
- Floor Finish: 1.5 KN/m2
- Seismic Code: NBC 105:2020.

- Time History: Imperial Valley 1979, EC County Center FF, 92, 0.2354g.
- Acceleration Time Series in Units of G, NPTS = 8000, DT = 0.005 Sec.
- Concrete Grade M20 and Grade of Steel is Fe500.
- Column: 300mm x 300 mm with 6 Number of 16mm diameter bars.
- Beam = All Beams of 230mm x 375 mm
- Slab = 150mm Thick
- Walls: 230 mm thick brick masonry wall
- Finite Element Software used = ETABS V 18.1.1

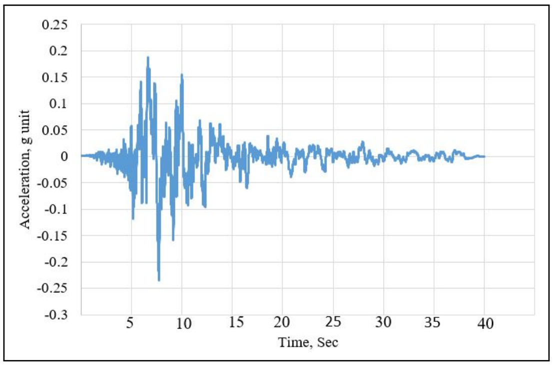

Figure 4: Imperial Valley 1979, 0.2354g

3.2 Viscous Damper Properties

Parameters such as velocity exponent alpha and damping coefficient C affect the performance of FVDs for protection of structure during seismic event. Selecting these parameters is essential for designing FVDs to obtain the optimal damping performance. Different values for the parameters as shown in Table 1. were used for analyzing within the 15 conditions. The nonlinear time-history analysis method was used to analyze the relationships among the damper parameters and structure responses.

The main structural responses for comparison with different viscous dampers parameters are Story displacement, Story Drift ratio, Base Shear and link force. The spring stiffness of damper has to be high to overcome buckling of damper and extender during any type of seismic event. The spring stiffness for damper is considered as 400KN/mm for all the cases. Dampers in diagonal corner distribution and Mid chevron (Double diagonal) distribution for four story RC frame building are shown in figure 5 and 6.

Table 1: Viscous damper properties.

Case	Damper Distribution	C , KN*(s/m)	alpha
I	Frame without Damper	0	0
II	Diagonal Corner	350	0.3
		700	0.3
		1050	0.3
		1400	0.3
		1750	0.3
III	Diagonal Corner	700	0.3
		700	0.6
		700	0.9
IV	Mid Chevron	350	0.3
		700	0.3
		1050	0.3
		1400	0.3
		1750	0.3
V	Mid Chevron	700	0.3
		700	0.6
		700	0.9

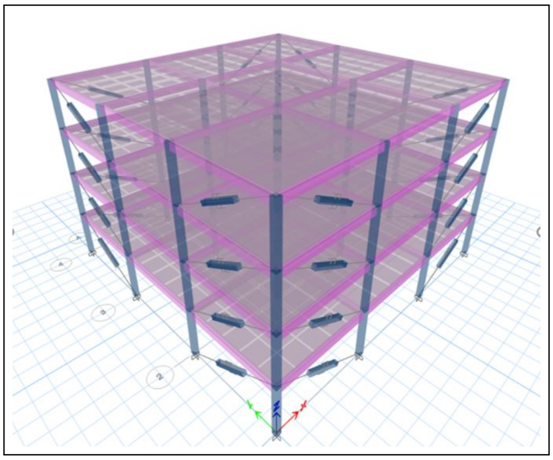

Figure 5: Diagonal Corner Distribution.

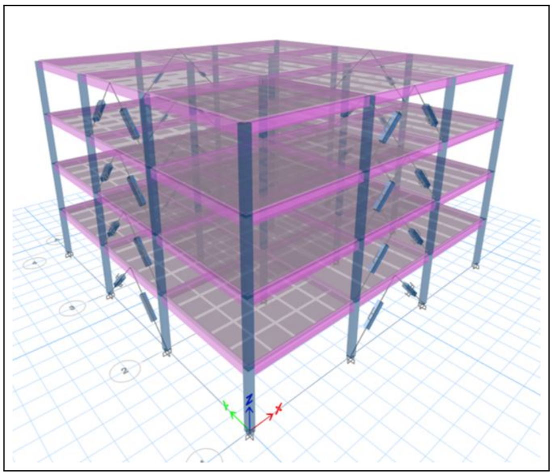

Figure 6: Mid Chevron (Double Diagonal) Distribution.

4. Results and Discussion

A Four storied reinforced concrete frame structure was taken to analysis to capture the effect of various parameters of fluid viscous damper on seismic performance of structure. The frame was subjected to time history of Imperial Valley 1979 earthquake along X direction and respective responses were noted.

4.1 The effect of various parameters on Story displacement:

After analysis of bare frame RC structure and structure with FVDs, roof top displacement was plotted in the respective figure for all cases. It has been observed that by increasing damping coefficient, the roof top displacement reduced gradually. By comparing case II and case III, we can say that lower value of velocity exponent has better performance in reducing the displacement responses. Between corner diagonal FVD and Mid chevron FVD distributions, earlier shows slightly better performance.

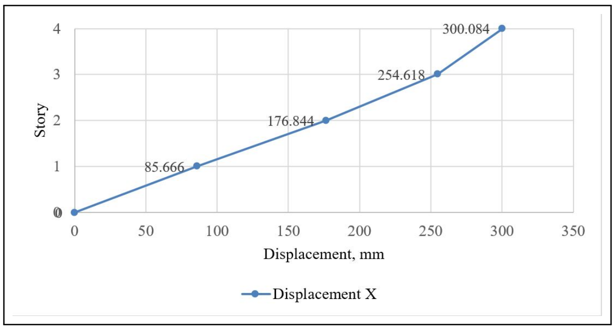

Figure 7: Case I Story displacement response

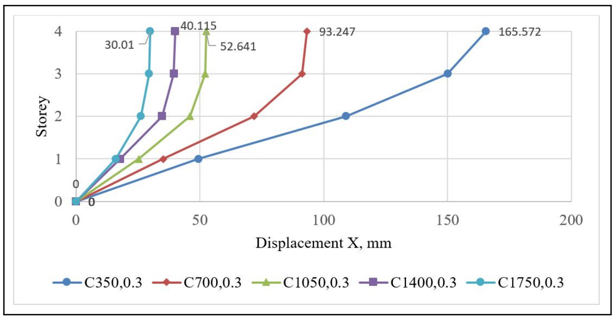

Figure 8: Case II Story displacement response

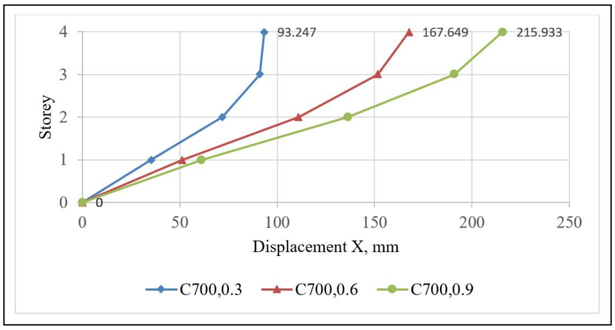

Figure 9: Case III Story displacement response

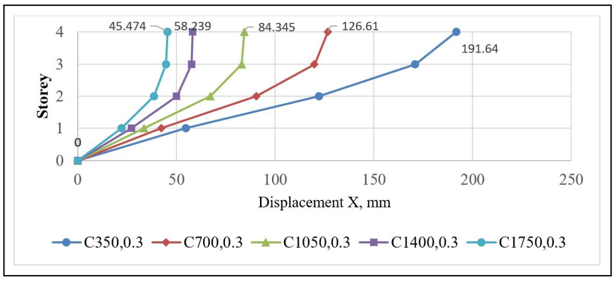

Figure 10: Case IV Story displacement response

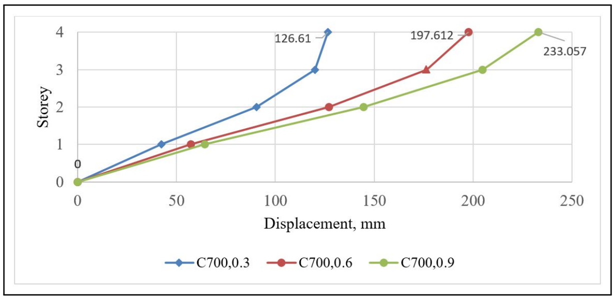

Figure 11: Case V Story displacement response

4.2 The effect of various parameters on Story Drift ratio:

Story drift was compared for all cases and concluded that more powerful viscous dampers reduced drifts more practically as shown in above figure. Optimum damping coefficient can be adjusted as per target drift performance of structure. For instance, if we set our target drift below 1 percent then for diagonal corner FVDs distribution we required damping coefficient and velocity exponent as 1050 KN*(s/m) and 0.3 but for mid chevron distribution we required 1400 KN*(s/m) and 0.3 value respectively. Like displacement response, lower drift is observed in corner diagonal FVD distribution than in mid chevron distribution. Case III and Case V showed that the damping exponent has more impact on drift reduction and lower exponent shows better performance.

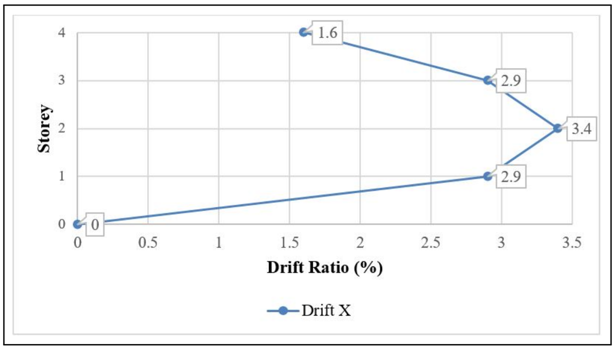

Figure 12: Case I Story Drift response

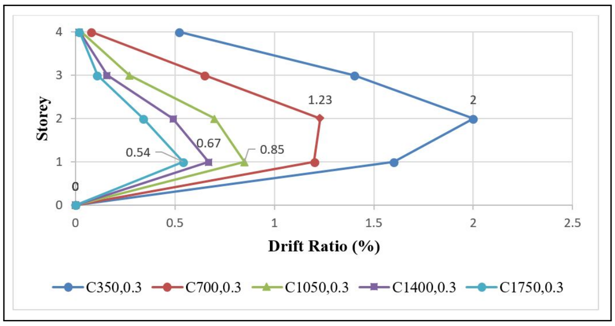

Figure 13: Case II Story Drift response

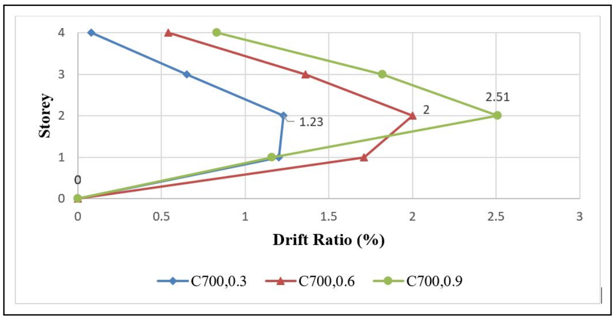

Figure 14: Case III Story Drift response

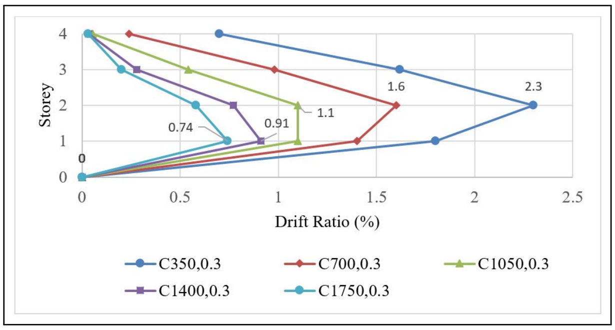

Figure 15: Case IV Story Drift response

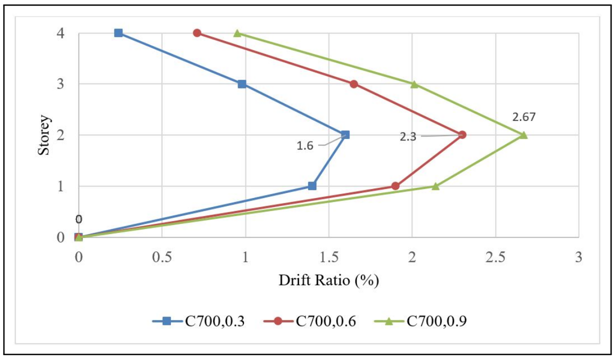

Figure 16: Case VI Story Drift response

4.3 The effect of various parameters on Base Shear:

After analyzing, results have shown that introducing FVDs in reinforced concrete structure can decrease base shear up to 25 percent. Case II and Case IV show that there is optimum damping coefficient value of lowest base shear induced in structure, for other values base shear will be higher. Case III and Case V suggest that increasing velocity exponent will increase the base shear.

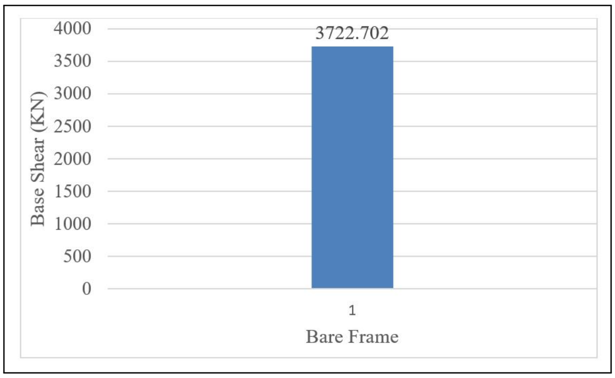

Figure 17: Case I Base Shear response

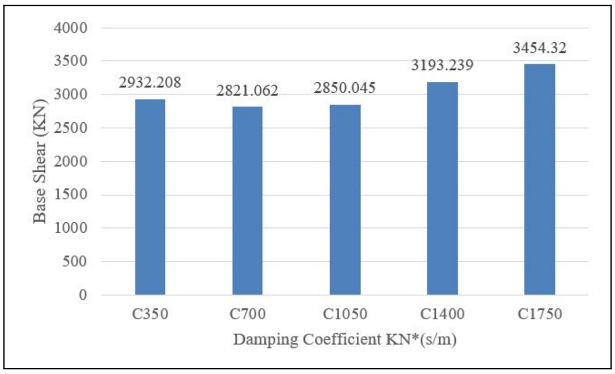

Figure 18: Case II Base Shear response

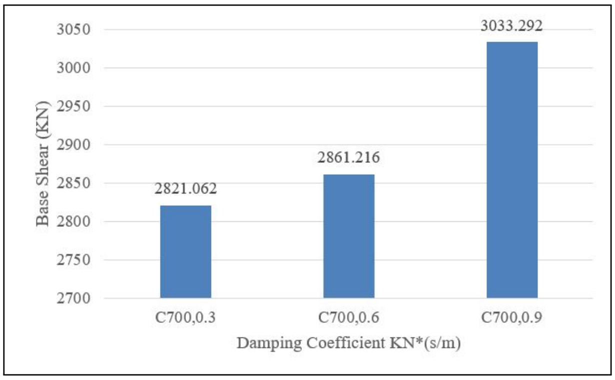

Figure 19: Case III Base Shear response

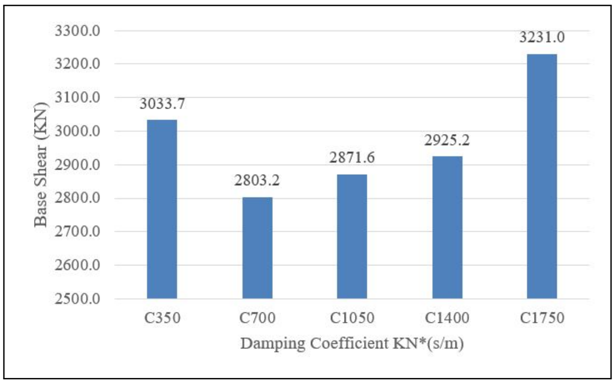

Figure 20: Case IV Base Shear response

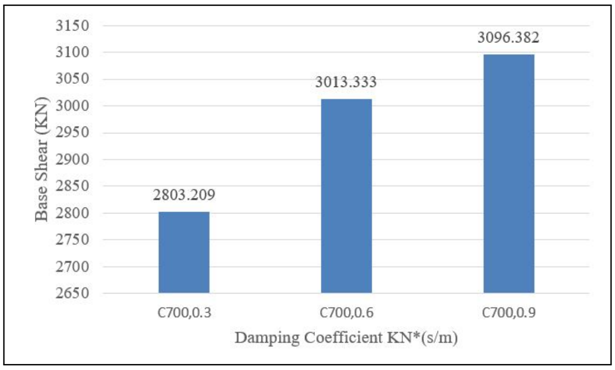

Figure 21: Case V Base Shear response

4.4 Discussion

Total of 15 set of analysis are carried out under 5 cases. In this study, dampers placed symmetrically along the perimeter corner show effective results compared to mid chevron (double diagonal) distribution. Seismic base shear decreased by 25 percent for four story RC frame structure with damping coefficient of 700 KN*(s/m) and velocity exponent value of 0.3 . This decrease in base shear is due to decrease in response spectrum for the design of structure under same seismic loading. Maximum pseudo spectral acceleration for four story frame building is reduced up to 60 percent of bare frame. This reduction of response spectra is due to increase in damping in addition of inherent damping of the frame structure. Decrease in base shear is only noticed for optimum damping coefficient value. Damping coefficient greater than optimum value will rigidize the structure which lead to induce more base shear. Higher value of damping coefficient will force the damper to act like steel bracing which will alter frequency of the structure.

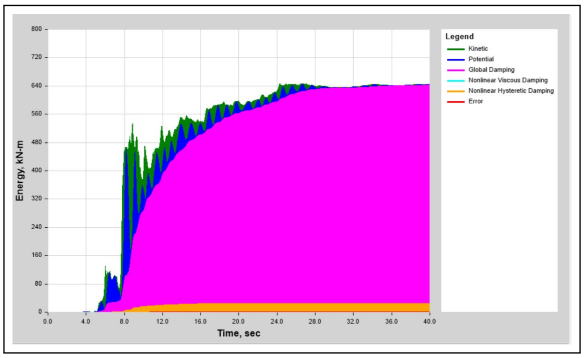

Figure 22: Cumulative Energy Component for Frame Structure without damper

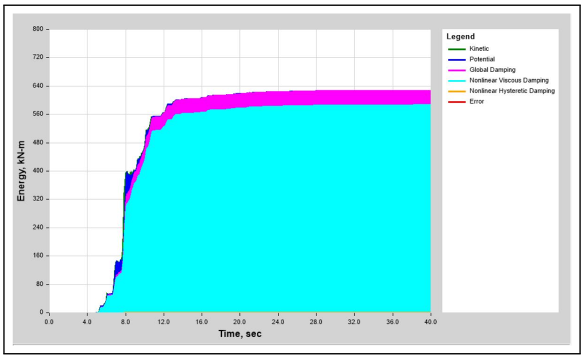

Figure 23: Cumulative Energy Component for RC Structure with damper C700,0.3

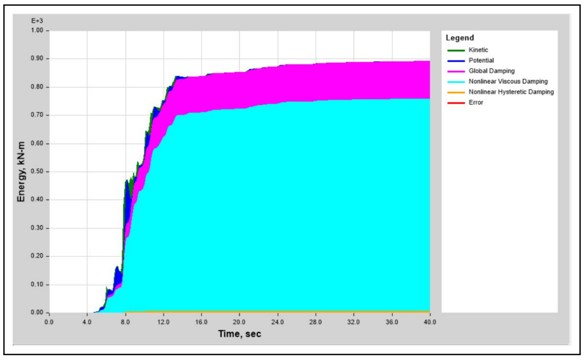

Figure 24: Cumulative Energy Component for RC Structure with damper C700,0.6

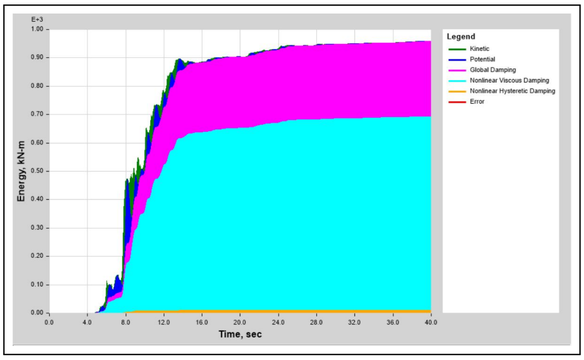

Figure 25: Cumulative Energy Component for RC Structure with damper C700,0.9

As the analysis proceed how the energy of the applied loading is dissipated by the structure itself or by any energy dissipating mechanism is shown on the figure 22,23,24,25. Figure 22 clearly depicts that large portion of energy is dissipated by global damping which is represented by pink graph portion. It is inherent viscous damping provided in FE model as damping matrix. In figure 23,24, and 25 major portion of energy is dissipated by Nonlinear viscous damping which is provided in structure in the form of fluid viscous damper. The result of this study show velocity exponent value of 0.3 with optimum damping coefficient will reduce the responses of the structure in efficient way comparing to higher value of velocity exponent of 0.6 and 0.9. A damping exponent of approximately 0.3 oftentimes provides an optimal combination of maintaining a high amount of energy absorbed per cycle. Fluid viscous damper with smaller velocity exponent produces larger damper forces at the ranges with lower velocities.

Diagonal corner damper distribution shows better results in controlling drift and displacement of four story RC frame structure compared to mid chevron (double diagonal) distribution. This is due to difference in angle of damper with horizontal. Diagonal corner damper makes an angle of 26.57 degree while mid chevron (double diagonal) makes an angle of 45 degree. (Constantinou et al., 2001) suggest that the significance of the configuration of the energy dissipation system is evident in the effect of the magnification factor on the damping ration. A damper selected to provide a damping ratio of 5 percent of critical with an angle of zero degree with horizontal will provide a damping ratio of 3.2 percent of critical with an angle of 37 degree with horizontal. Author also added that the same damper that provide the damping ratio of 5 percent in earlier case if used in the toggle brace configuration, the damping ratio will increase.

5. Conclusions

In this study, a four story and an eight story RC structure were analyzed under the Imperial Valley 1979 Earthquake. The study include the symmetrical RC frame combined with Fluid viscous dampers, was carried out to investigate various parameters' effect on the reduction of seismic responses. The following are the conclusions that can be drawn from the present study.

1. Addition of FVD reduces the story displacement and story drift of the structure by selecting suitable damper parameters. The damping coefficient cannot be excessively large because it leads to rigidize the structure and tends to have larger base shear and output forces beyond the product scope. On the other hand, the damping coefficient value ought to create the extra damping ratio to meet the expected performance.
2. The lower the velocity exponent the more efficient the viscous damping for seismic energy dissipation. In this study velocity exponent of 0.3 shows better option in reducing response of undertaken structures.
3. Nonlinear viscous damper reduces Seismic base shear by 25 percent for four story RC frame structure with damping coefficient of 700 KN*(s/m) and velocity exponent value of 0.3 respectively. This study concludes that selecting damping coefficient value greater than optimum value will lead to increase the seismic base shear.
4. Diagonal corner damper distribution is more effective than mid chevron (double diagonal) distribution for reducing the responses of the four story RC frame structure. Present study in combination of earlier studies suggest change in angle and configuration of damper and bracing lead to higher damping ratio for same damping parameters.

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