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A Study on Seismic Response of Reinforced Structures Retrofitted with Fluid Viscous Dampers in Shear Walls

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Abstract: This paper investigates the seismic behavior of multi storey building using damping devices strategically located within the lateral load resisting elements (shear wall). The study concentrates on a retrofitting strategy with passive energy dissipation device known as Fluid Viscous Damper (FVD) which can be used to retrofit existing buildings to ensure seismic safety by fitting damping devices which can transform a wall panel into a damping element. Nine, Eighteen and Twenty seven storey shear wall structures with three cut out sections provided at different storey levels were analyzed using software SAP2000 to obtain its seismic behavior without and with linear FVD retrofitting so as to obtain an optimum damper location and results were compared with respect to peak roof deflection and roof acceleration.Time history analysis is used in the study and results indicate that dampers provided at lower levels as well as at the places of maximum interstorey drifts in shear wall showed reduction in seismic response.

Keywords: *Seismic response; Shear wall; Displacement; Acceleration.*

1. Introduction

Multi-storey buildings contain shear walls around the elevator shafts and stairwells to resist lateral loads. Shear walls usually does not show ductile behavior since these structures suffer damages due to earthquakes. Some of failures occurring in shear walls are flexure, shear, in plane splitting and rocking failures. These structures need to be strengthened to resist future earthquakes and the process of making the structure more resistant to any future earthquakes is known as seismic retrofitting. The use of passive energy dissipation devices has become very popular in recent years to control the vibration response of high rise buildings during seismic events .However, the vast majority of applications were emphasized within the frame structures, and use of damping devices within cut outs of shear wall is limited.

Madsen et al. (2003) studied seismic response of building structures with viscoelastic damper placed within the cut out sections of shear walls for which finite time history analysis were carried out and results indicated that dampers provided at the lower levels of shear wall showed greater improvements in seismic response [1]. Kamath et al. (2012) studied on seismic retrofitting of a six storey steel moment resisting frame (MRF) with FVD (Fluid Viscous Dampers) which were analyzed in ETABS software and results were compared with respect to peak storey and inter-storey drifts without and with retrofitting of linear FVD.It was found that retrofitting with FVD's significantly reduced the seismic demand [2]. Further another study conducted by Kamath et al. (2012) on retrofitting of a nine storey RCC structure with FVD with chevron bracing configuration and it was found that there was significant reduction in seismic demand in terms of peak storey drifts, interstorey drift and pseudo spectral accelerations [3].Constantinou and Symans (1992) documented experimental and analytical study of seismic response of structures with supplemental fluid viscous dampers. In the report they have verified mechanical properties of FVD through an experiment and found that Fluid Viscous Dampers are capable of achieving and surpassing the benefits offered by active control systems with additional benefits of low cost, longevity and reliability [4].Hwang (1998) studied viscous dampers and its practical application issues for the Structural Engineer. The author addresses various issues such as selection of fluid viscous damper solution, overview of existing design guidelines and design with fluid viscous dampers [5]. The present study was conducted with the use of FVD provided at three cut out sections of shear walls at various storey levels. FVD consists of a hollow cylinder filled with fluid, this fluid typically being silicone based. When the damper piston rod is stroked, fluid is forced to flow through orifices through piston head which results in differential pressure across the piston head producing very large force that resist the relative motion of the damper. As the fluid flows at high velocities, it results in the development of friction between fluid particles and the piston head. The friction produces heat which is dissipated through the body of the FVD. FVD and its parts are shown in Figure1.

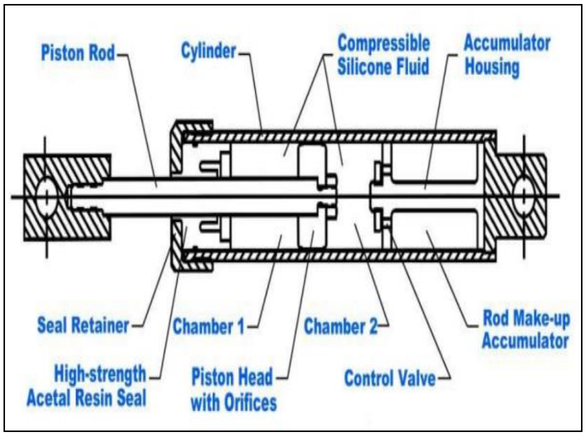

Figure 1: *Fluid Viscous Damper*

Advantages and disadvantages of these FVD has been studied and documented by Hwang (1998) [5].The equation for the force in FVD is given by FEMA (Federal Emergency Management Agency) 273(1997) [6] is as follows, $F = C_0|\dot{D}|^{\alpha}\, Sgn(\dot{D})$

Where F=Force in dampers. C_0=Damping co-efficient for the device. α=Velocity exponent for the device (for linear FVD, α=1.D=Relative velocity between each end of the device and sgn is the signum function that defines the sign of the relative velocity term. K_{linear} (stiffness of the damper) is made zero to achieve pure damping (C_{linear}) in the present study which are incorporated in shear wall

2. Methodology

2.1. Model Description

In the present study, a 2 dimensional model of nine, eighteen and twenty seven storey structure with cut out sections were developed and analysed in SAP2000.It consists of a rectangular shear wall of size 6m wide by 0.2m thick. Columns and beams have cross sections of 0.4m×0.4m and 0.23m×0.4m respectively. The height between the floor levels is 3m.A lumped mass of 50,000 kg were placed at each node of the column that intersected the floor level so that column could ideally bore the entire gravity load and shear wall could mainly resist lateral load. Shear wall has been modelled as shell elements with meshing. FVDs have been modelled as link elements .FVD's are assumed to provide pure damping considering effective stiffness of damper as zero. At each of the floor levels shear wall and column were connected by rigid links to stimulate the rigidity of the floor slabs and to transfer lateral load into the wall. These rigid links were modelled as beam elements by providing beam constraints in SAP 2000 software [7], where this type of constraint, links two nodes (nodes between column and wall) which forces translations and rotations at the first node to be same as at the second node and to transfer the lateral load into the wall.

Three cut out sections were provided at different levels of the structure i.e. 1-3,4-6,7-9 for 9 storey,1-3,4-6,7-9,10-12,13-15,16-18 for 18 storey and similar cut out sections were provided for 27 storey as shown in Figures 3,4 and 5 respectively. These structures were analysed, retrofitted with and without FVD and their response were studied. Details of the damper location within the shear wall can be seen in Figure 2 where a 4m wide by 2.5m high wall sections were cut out and replaced by two diagonal dampers

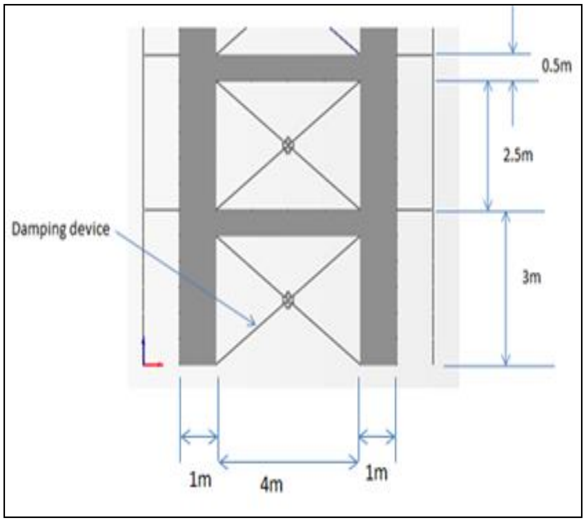

Figure 2: *Details of damper placement and dimensions of shear wall*

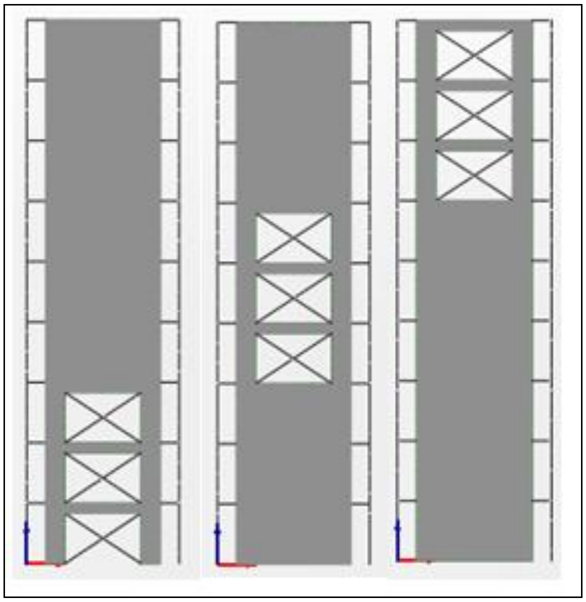

Figure 3: *Damper locations for 9 storeys*

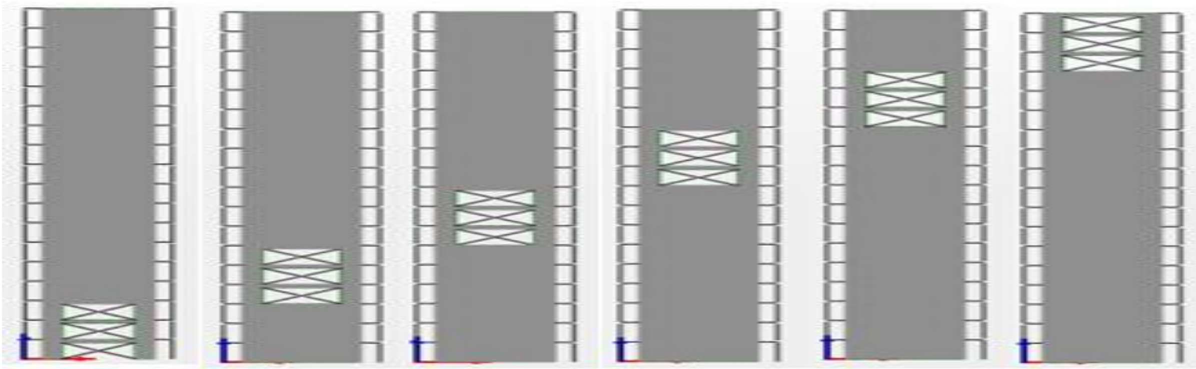

Figure 4: *Damper locations for 18 storeys*

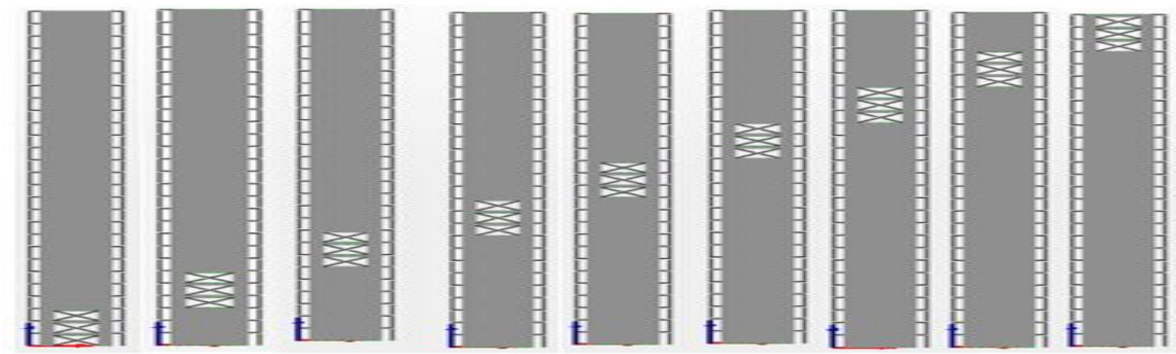

Figure 5: *Damper locations for 27 storeys*

2.2. Design of Ground Motion Analysis

The response of these models are investigated from records of past earthquakes occurred in the California region. The first two accelerograms, LA03 (El Centro Array 5, James road) where LA stands for Los Angeles LA06 (El Centro Array 6) are taken from 1940 El centro earthquake with peak ground acceleration (PGA) of 0.386g and 0.23g respectively, the third accelerogram LA14 (Northridge LA County Fire Station) is from the 1994 Northridge Earthquake with PGA of 0.64g.Accelograms of these earthquakes are shown in Figure 6, 7 and 8.

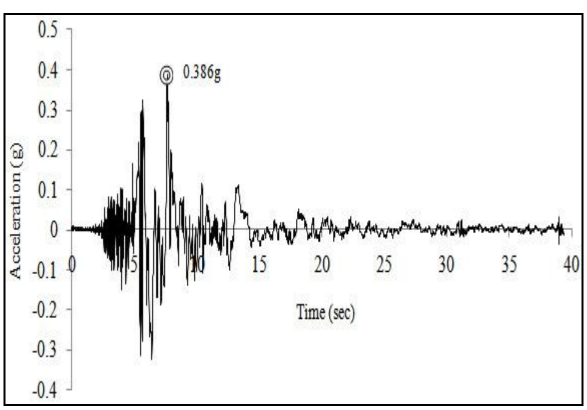

Figure 6: *Accelerogram of LA03*

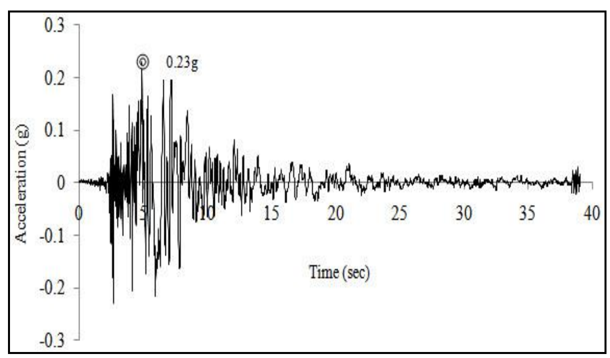

Figure 7: *Accelerogram of LA06*

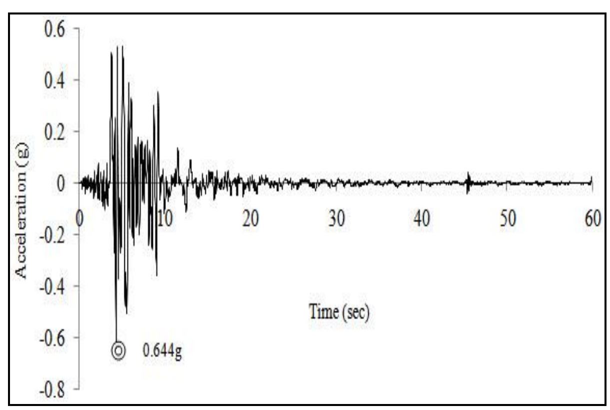

Figure 8: *Accelerogram of LA014*

2.3. Procedure to Obtain Damping Coefficient

Details of the formulae used in the study are given by Rastogi et.al (2011) [8].A lateral stiffness distribution is obtained by applying a unit load at the top and stiffnessof storeys are calculated with respect to top storey. The structure is assumed to have an inherent damping (ξ_I) in this case it is 5% of critical. FVD's are assumed to provide remaining damping (ξ_V), usually around 30% of critical damping. Thus the overall damping would be then $\xi = \xi_I + \xi_V$. Damped time period is then given by $T_d = \frac{T}{\sqrt{(2\xi v+1)}}$. Where T=Period of the structure without dampers. A pair of springs are then introduced in the cut out sections of specified FVD location with trial stiffness k_{0tr} and distributed accordingly to the lateral stiffness and its time period T_{tr} is then calculated. If $T_d = T_{tr}$, then $k_0 = k_{0tr}$, if it doesn't match entire procedure is repeated with new spring stiffness.

$$k_0^n = \frac{k_{0tr}^n}{1 - \left(\frac{T_d^2 - T_{tr}^2}{T_d^2 - T^2}\right)}$$

Once the value of k_0 is calculated, the coefficient of viscous damping C_L can be calculated as $C_L = \frac{k_0 T}{2\pi}$.The entire procedure is illustrated in Figure 9.

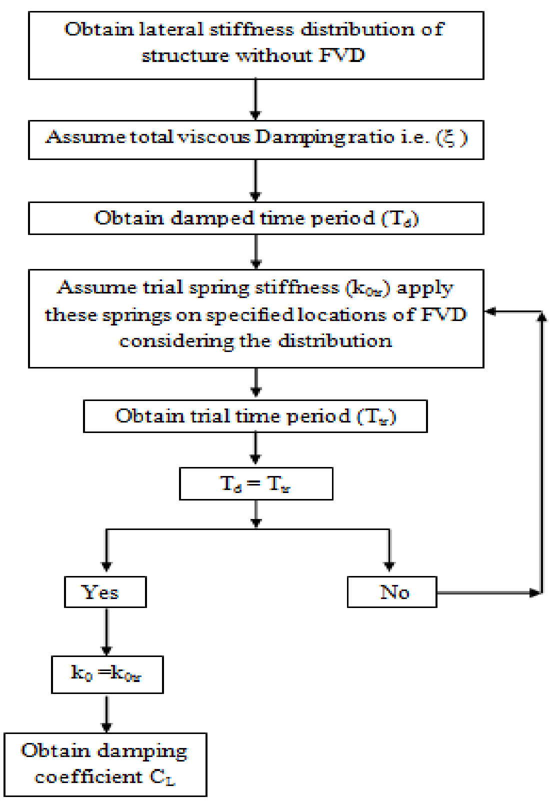

Figure 9: *Flow chart of procedure to obtain damping coefficient for FVD*

3. Results and Discussion

A linear time history analysis were performed on the structure, considering three different accelerograms without and with retrofitting of shear walls using FVD and its responses were studied. Time period obtained for nine, eighteen and twenty seven storey of the wall and walls with cut out section at various levels are shown in Table 1,Table 2 and Table 3.For nine, eighteen and twenty seven storey structure the maximum reduction were found to be 74.10% for LA06,63.58% for LA06 and 58.29% for LA03 respectively were the cut out sections were provided at the bottom three storeys as shown in Figures 11,14 and 16 .Results from time period for all three the structures indicate that when cut out sections are provided at the bottom three storeys, there is increase in the time period with respect to the structure with no cut outs in the shear wall. By reducing the stiffness at the base of the structure, there is increase in the time period and so reduces the amount of seismic energy attracted towards it.For eighteen and twenty seven storeys, reductions were also seem to be significant were the interstorey drifts were more .i.e. reduction of 62.58% by providing cut out sections at the 10-12 storey levels for eighteen storey and reduction of 55.95% at 13-15 storey levels for twenty seven storey as shown in Figures 13 and 16 respectively. Time history plot function of roof acceleration of 27 storey with cut out sections provided at 1-3 for LA06 and 13-15 storey levels for LA14 are shown in Figures 18 and 19.Roof acceleration reduction for 27 (1-3) were found to be 57.14% and for 27(13-15) reduction of 63.14% for LA14.

Table 1: *Time period for 9 storeys*

Cut outs	Time period (sec)
-	0.109
(1-3)	0.139
(4-6)	0.09
(7-9)	0.089

Table 2: *Time period for 18 storeys*

Cut outs	Time period (sec)
-	0.254
(1-3)	0.269
(4-6)	0.22
(7-9)	0.211
(10-12)	0.202
(13-15)	0.189
(16-18)	0.193

Table 3: *Time period for 27 storeys*

Cut outs	Time period (sec)
-	0.377
(1-3)	0.425

(4-6)	0.344
(7-9)	0.337
(10-12)	0.331
(13-15)	0.399
(16-18)	0.315
(19-21)	0.388
(22-24)	0.293
(25-27)	0.313

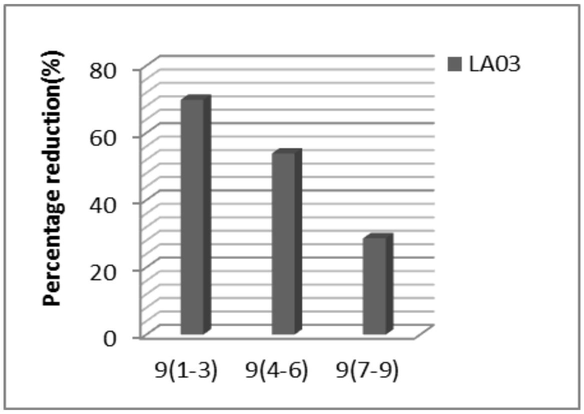

Figure 10: *Peak roof deflection reduction for 9 storeys for LA 03*

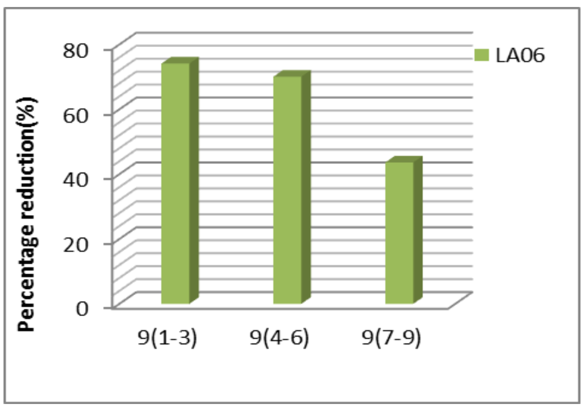

Figure 11: *Peak roof deflection reduction for 9 storeys for LA06*

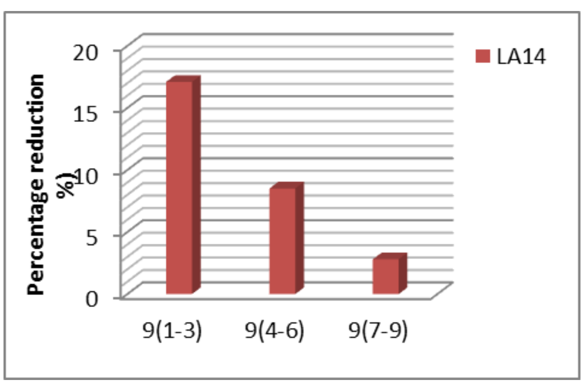

Figure 12: *Peak roof deflection reduction for 9 storeys for LA14*

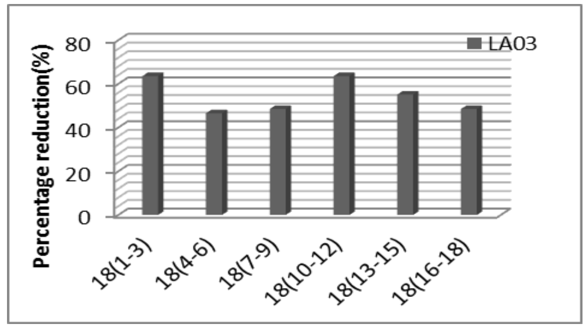

Figure 13: *Peak roof deflection reduction for 18 storeys for LA03*

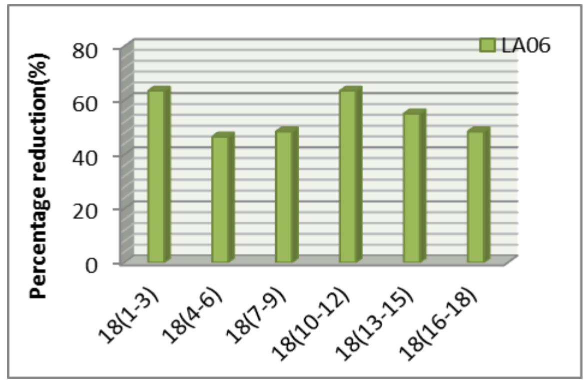

Figure 14: *Peak roof deflection reduction for 18 storeys for LA06*

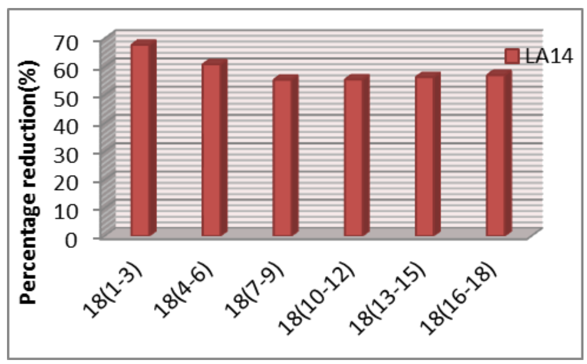

Figure 15: *Peak roof deflection reduction for 18 storeys for LA14*

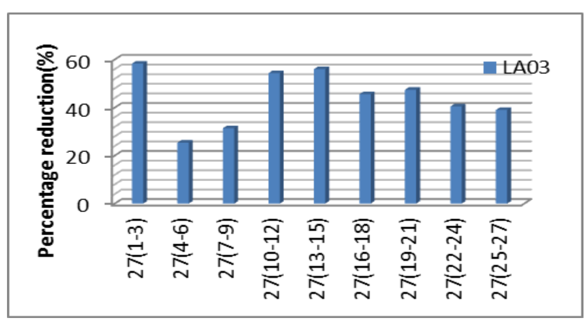

Figure 16: *Peak roof deflection reduction for 27 storeys for LA03*

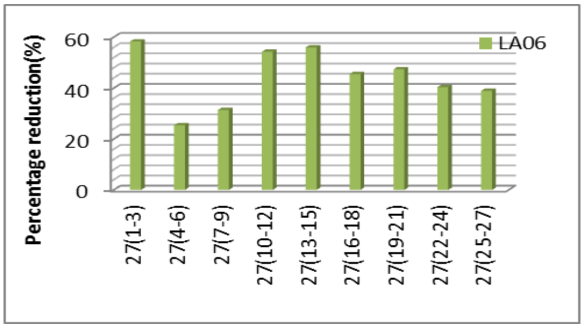

Figure 17: *Peak roof deflection reduction for 27 storeys for LA06*

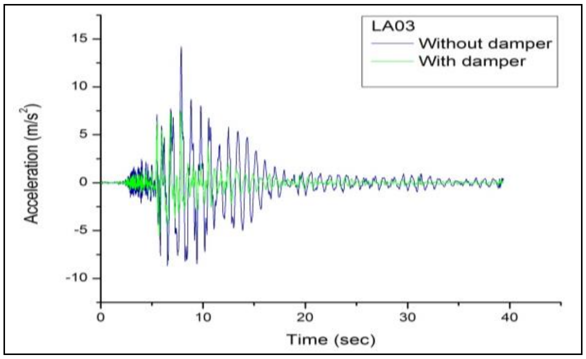

Figure 18: *Time v/s Roof acceleration plot for 27(1-3) for LA03*

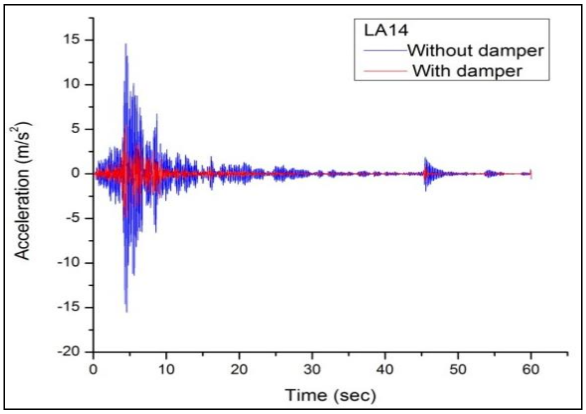

Figure 19: *Time v/s Roof acceleration plot for 27(13-15) for LA03*

4. Conclusions

From the discussions of results following conclusions are made.

1) Damper provided at the cut out sections of shear showed substantial reduction in seismic response.
2) By placing dampers in the cut out sections at the bottom three storey levels for nine, eighteen and twenty seven storey, maximum reduction in peak deflection were achieved.
3) For eighteen and twenty seven storey structures, reductions were also seen to be maximum at the regions were inter storey drift were more however this might be different for other type of dampers.
4) Reduction in peak acceleration leads to lesser inertia forces and hence increases the ability of the structure to cope up with seismic events.

5. Acknowledgments

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