Seismic Response Study of RCC Buildings with Elasto-Plastic Viscous

Jisha J.S, Jean Molly Simon

Abstract—Supplemental damping devices dissipate earthquake-induced energy through either hysteretic action or viscoelastic or viscous action. In this work the damping device selected is elasto-plastic viscous damper, which have elasto-plastic and viscous properties. It can be act as both energy dissipating device as well as structural element. The current work presents a framework for studying the effect of elasto-plastic viscous dampers on seismic performance of buildings using SAP2000. 9-storey reinforced concrete building was modeled using SAP2000 software. The modeled building was performed nonlinear time history analysis. Based on the minimum displacement criteria position of dampers has been located. Seismic response of six plan configurations and twelve damper configurations were evaluated. Seismic responses of RCC building with and without elasto-plastic viscous dampers were also investigated.

Index Terms—Effective damping coefficient of dampers, elasto-plastic viscous dampers, stiffness of dampers, time history earth quake analysis and viscous dampers

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1 INTRODUCTION

Failure of structures especially buildings, which may be caused due to earthquake ground motion leads to human injury and economic loss. There are many existing structures that do not satisfy the present seismic code specifications. Safety of such structures under earthquakes is not adequate. The traditional approach to design an earthquake resistance building is to provide adequate strength and stiffness against earthquake forces. As an alternative, studies have developed the use of active and passive structural control systems. Many researches have been conducted to derive analytical models for dampers and to verify the effect on structural control. Previous studies showed that dampers can increase structural damping significantly, which brings the decrease of structural responses, such as displacement and absolute acceleration. Giuseppe Oliveto and Massimo Marletta (2005) discussed seismic retrofitting of reinforced concrete buildings using traditional and innovative techniques. They reviewed traditional methods of seismic retrofitting and identified the weak points. E. Tubaldi et al., (2014) introduced an efficient methodology for assessing the seismic risk of structural systems equipped with linear and nonlinear viscous damping devices. He formulated a reliability-based assessment problem. He also introduced an efficient technique for seismic assessment of linear elastic systems with dampers. George D. Hatzigeorgiou et al., (2014) examined the inelastic response behavior of structures with supplemental viscous dampers under near-source pulse-like ground motions. A new method was developed for the evaluation ofeffective velocities and damping forces for structures with supplementalviscous dampers under near-source earthquakes. The study focuses on single-degree-of-freedom systems with elasto-plastic behavior and for seismic faults with strike-slip and reverse or oblique reverse mechanism. Ras. A et al., investigates efficiency of different damper plan locations of viscous damper for a twelve storied moment resisting frame. F. Hejazi et al., (2014) formulated a constitutive law and finite element model for three dimensional nonlinear viscous damper as a structural member. These types of dampers are called elasto-plastic viscous dampers (EPVD). He also proposed the analytical model and finite element algorithm. But he didn’t discuss anything about practical application location of EPVD. This investigation deals with performance of 9 storey reinforced concrete building for different vertical locations of dampers. .

2 ELASTO-PLASTIC VISCOUS DAMPERS

Elasto-plastic viscous damper (EPVD) consists of three different zones. The first zone is the rigid block zone located at each end of the member. The second zone is the 3D plastic hinge Zone at each end, which is indicated by the damper connection failures and assumed. The remaining inter-mediate part of the member represents the third zone, which is a function of the viscous damper properties. The central part of the member is assumed to reflect the elastic behaviour of the member, while the plastic hinge zones reflect the inelastic behaviour of the member. It has a high lateral stiffness, in addition to providing damping. Different connection configurations are available for connecting damperelements. But one of the most commonly used simple and economical configuration is diagonal configuration[3].

3 MODEL GEOMETRY

9 storey residential building with 3 bays along X-direction and 2 bays along Y-direction was selected for the study. Foundation system is considered as footing with Raft slab as per the

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Geotechnical recommendations.

The horizontal structural system consists of flat slab. Beams are provided all along the periphery of the building as well as the inner frames. Building details are provided in Table 1.

TABLE 1.
Building details

Sl. No.	Content	Description
1	Type of Structure	Multi story moment resisting frame
2	Seismic Zone	III
3	Zone Factor	0.36
4	Number of Storey	3 storey and 9 storey
5	Base Floor Height	4.5 m
	Floor Height	3m for all other floors
7	Wall Thickness	External-230mm & Internal-115mm
8	Materials	M25 Concrete & Fe415 steel
9	Size of Column	400*400
10	Size of Beam	300*400
11	Depth of Slab	120mm
12	Weight of RCC	25KN/m^3
13	Lumped mass	9360kg @ floor level 8653kg @ roof level
14	Live Load	3KN/m^2 @ floor level & 1.5KN/m^2 @ roof level
15	Type of Soil	Medium
16	Importance Factor	1

4 MODELLING OF REINFORCED CONCRETE BUILDING FRAME

SAP 2000 is an efficient finite element modelling software. The required building has been modelled and analysed using SAP 2000. The superstructure is modelled as a three dimensional linear elastic system. Base is assumed to be rigid in plane and it was modelled using three degrees of freedom as per IS: 875(Part-2)-1987. The building is assumed to be in seismic zone III. Plan of the building is given in the Fig 2.

Fig. 1 Plan of the building

The material properties mass per unit volume, modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, type of material, IS code details etc. were assigned. Beams and Columns are modelled as frame elements while flat slabs were modelled as shell element. Section details for beam and column elements also directly assigned to the structure. Fig 4 shows three dimensional views of modelled 9 storey building frame. In this model the load cases considered are dead load, live load and Elcentro earthquake acceleration (Imperial Valley – 1940). The static loads, dead load and live load on the structure have been assigned as uniformly varying load. The dynamic seismic load has been applied as Elcentro time history function.

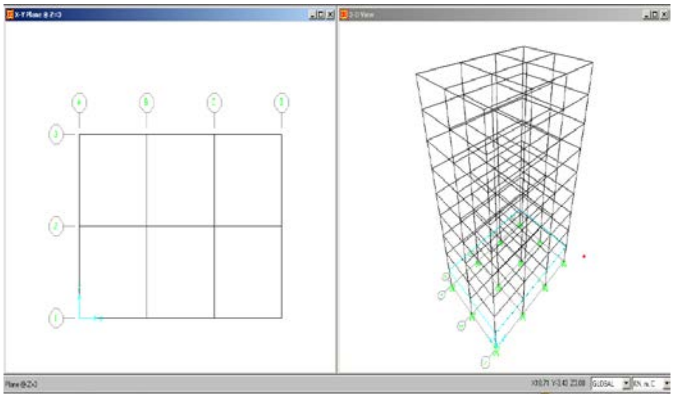

Fig. 2 Modelled 9 Storey Building Frame

5 MODELLING OF DAMPER ELEMENTS

Damper properties were computed based on the frequency and shearing deformation values from the analysis results of structures without damper. Dampers elements have been modelled as a bi-linear spring and dash-pot in parallel known as the Kelvin model. The spring represents stiffness and the dashpot represents damping element. Abbas and Kelly (1993) defines the stiffness and damping coefficients as follows

$$Kd = G'A/t \qquad (1)$$

$$Cd = G''A/\omega t \qquad (2)$$

Where A, is the shear area of the damper material, t, is the thickness of the material, ω loading frequency of damper. G′ is the shear storage modulus and G″ is the shear loss modulus. Equations of G′ and G″ are given below

$$G' = 16.0\omega 0.51\gamma\text{-}0.203e\ (72.46/Tem) \qquad (3)$$

$$G'' = 18.5\omega 0.51\gamma\text{-}0.20e\ (73.89/Tem) \qquad (4)$$

Where, γ is the shear strain. The temperature was kept constant at 21oC during the entire study. The properties of damping for models were calculated as effective stiffness as 10.2 x 106 N/M and effective damping coefficient as 61.64 x 106 Ns/m by using equations 6.1 to 6.4. The defined model of damper was connected diagonally to the reinforced building frame as two link element. Position of dampers was located by minimum deflection criteria. As per Clause no. 7.11.1 of IS 1893(Part 1):2002, the peak storey drift in any storey due to specified design lateral force with partial load factor of 1.0, shall not exceed 0.004 x hs, where hs is storey height.

5.1 Location of Damper Element

One of the main objectives of this study was to investigate the efficiency of dampers in deflection control for variety of placements under earthquake loading. Positioning of dampers was carried out by selecting best plan locations as well as elevation location based on minimum deflection under seismic excitation. For the study 6 different plan locations have been considered. The different plan configurations are designated by P1, P2, P3, P4, P5 and P6. In order to obtain the best plan configuration the damper elements were provided throughout the length at different bay locations. Pattern of different plan locations are given in the Fig. 5. The dark lines indicate location of damper element.

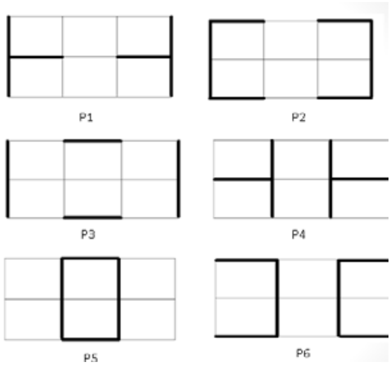

Fig. 3 Plan Configurations

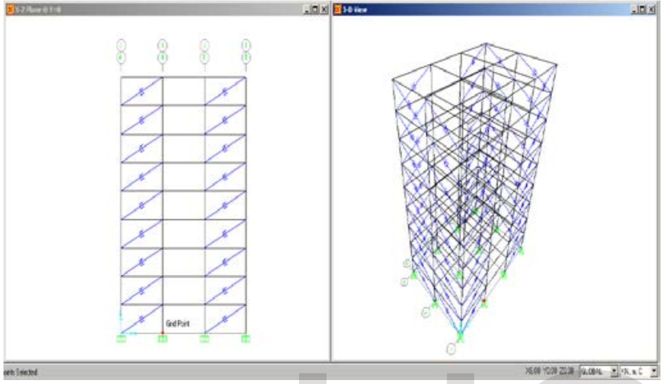

Fig 4 Nine Storey Building with Damper Elements

TABLE 2
Vertical Damper Configurations

Case	Designation	Position of damper
Case 1	E11 E12 E13 E14	Only in ground floor Only in 3rd floor Only in 5th floor Only in 7th floor
Case 2	E21 E22 E23	Ground floor and 1st floor 3rd and 4th floors 6th and 7th floors
Case 3	E31 E32 E33	Ground floor, 1st and 2nd floor 3rd, 4th and 5th floors 6th,7th and 8th floors
Case 4	E51	Alternate floors throughout the length
Case 5	E91	All floors

Four elevation configurations cases were selected for the comparative study. Designation details of vertical damper configurations are given in the Table 2 and Fig. 6.

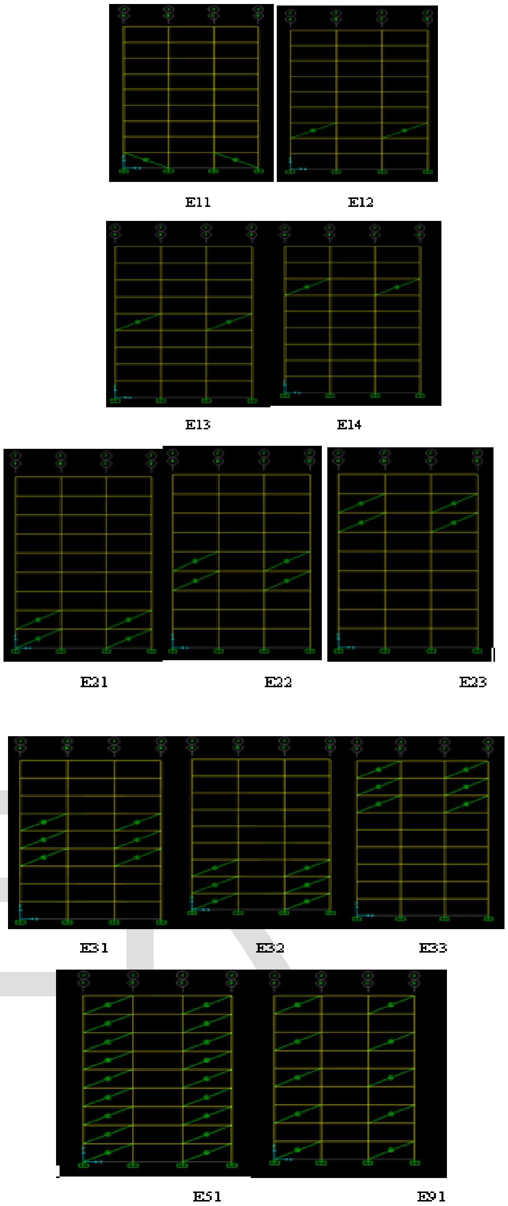

Fig 5 Vertical Damper Configurations

6 ANALYSIS OF STRUCTURES

The modelled structures were subjected to the Elcentro earthquake acceleration (Imperial Valley – 1940) with duration of strong motion 1.5 to 5 seconds and dominant frequencies in the range 0.39 to 0.639.The input function of Elcentro earthquake was North South Component with 1559 points at equal spacing of 0.02 seconds.. Fig. 8 shows north south time history function of Elcentro earthquake defined by SAP 2000 software. From the time history analysis, the time dependent dynamic responses of the building for the whole duration of the earthquake excitation, the base shear, displacement, shears, moments and axial loads of the elements at various amounts of earthquake ground motions have been determined. From the analysis results seismic behaviour of buildings with different damper configurations were studied. Time history analysis results of buildings with and without elasto-plastic viscous dampers also compared.

7 RESUTS AND DISCUSSIONS

Results obtained from time history were evaluated based on the seismic response of buildings. The base shear, displacement, shears, moments and axial loads of the elements at various amounts of earthquake ground motions were examined. The time history analysis for buildings with and without dampers has been compared in order to check the performance of elasto-plastic damper element.

7.1 Results of Different Plan Configurations

Different plan configurations were denoted as P1, P2, P3, P4, P5 and P6. The fundamental period for all the types of configurations is first mode. The maximum deflection has been occurred in the top floor for all the plan configurations. The maximum top floor deflection of 3 storey and 9 storey building for different plan configurations are given in the Table 3.

TABLE 3
Top floor deflections for different plan configurations

Plan configuration	Top storey deflection (m)	% Reduction
A3 & A9	0.24636	-
P1	0.19629	20.32
P2	0.19623	20.34
P3	0.19626	20.33
P4	0.22368	9.2
P5	0.22083	10.36
P6	0.21986	10.76

Time history analysis results of 9 storey building for different damper configurations are given in the Table 2 From the results it is observed that the configurations P1, P2, and P3 show comparatively low top storey displacement. The deflections of building at different storey heights for different damper configurations are plotted in the Fig.9. Behaviour of 9 storey building with damper configuration P4, P5, and P6 are similar. The percentage reduction is nearly 10%.

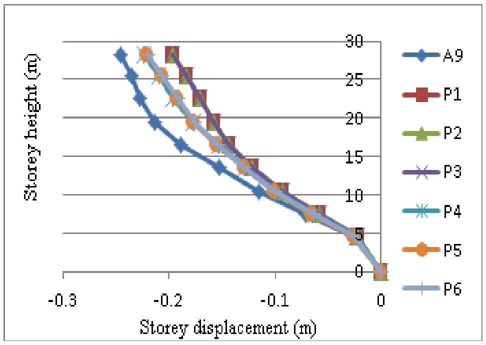

Fig. 6 Deflections of 9 storey Building at Different Storey Heights

7.2 Results of Vertical Configurations of Dampers

The time history analysis of 9-storey bare frame model and 12 damper configurations in the vertical direction subjected to Elcentro earth quake loads was carried out using SAP2000 software.

Case 1:The top storey deflection obtained for different damper cases are tabulated in the Table 4. From the table it is evident that the top storey deflection reduction of all the cases shows similar values. Among these result E12 shows minimum top storey deflection. It may be due to the maximum storey drift is located on third storey level.

TABLE 4
Top Storey Deflection for Case1

Top storey deflection in (m)				
Bare Frame	E11	E12	E13	E14
-0.24636	-0.2402	-0.23374	-0.23788	-0.24454
-0.23527	-0.23127	-0.21952	-0.22486	-0.23453
-0.22767	-0.22221	-0.21056	-0.21297	-0.22339
-0.21378	-0.20745	-0.19247	-0.19756	-0.20403
-0.18825	-0.18226	-0.16553	-0.17445	-0.17539
-0.15277	-0.14732	-0.13491	-0.14164	-0.14312
-0.11449	-0.11109	-0.10087	-0.10837	-0.10551
-0.07073	-0.06822	-0.06374	-0.06733	-0.06395
-0.02584	-0.02478	-0.02368	-0.02455	-0.0236

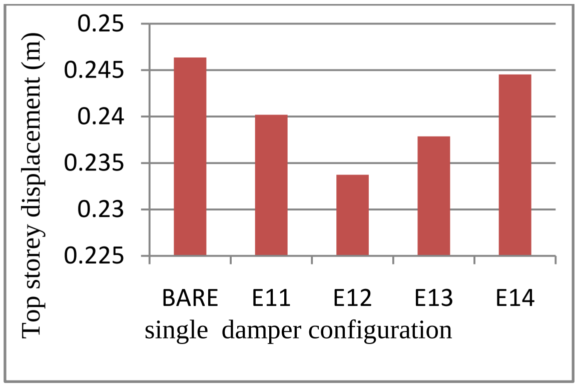

Fig 7 Top Storey Deflection of Case 1

Fig 10 shows top storey deflection of different single storey locations of damper device. The top storey deflection is reduced when the damper location is moving from the ground floor to the upper floor level up to third storey level. There after the deflection increases. Deflection is lower when the dampers are located in the top storey location.

Case 2:In this case dampers are located on any two adjacent stories. The top storey deflection obtained for different damper cases are tabulated in the Table 5

TABLE 5

Top Storey Deflection for case 2

Top storey deflection in (m)			
Bare frame	**E21**	**E22**	**E23**
-0.24636	-0.22855	-0.23577	-0.25295
-0.23527	-0.21589	-0.21926	-0.23717
-0.22767	-0.20656	-0.19783	-0.2223
-0.21378	-0.18991	-0.17637	-0.20011
-0.18825	-0.1638	-0.15247	-0.16785
-0.15277	-0.1317	-0.124	-0.13427
-0.11449	-0.09761	-0.09642	-0.09972
-0.07073	-0.05975	-0.05991	-0.06189
-0.02584	-0.02246	-0.02162	-0.02266

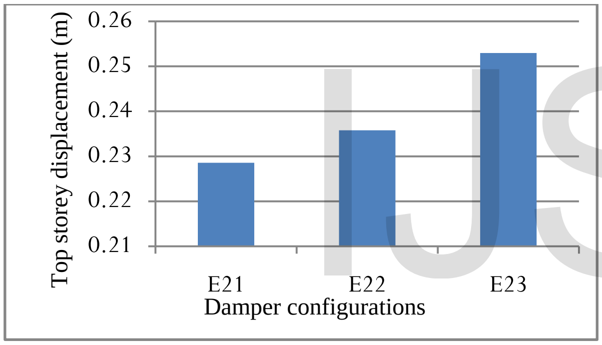

Fig 8 Top Storey Deflection of Case 2

From the Table 5, it is evident that the top storey deflection increased when the damper location moving from ground storey to upper storey levels. Among these result E21 shows minimum top storey deflectionFig 11 shows top storey deflection of different double storey locations of damper device. From this figure it is evident that, displacement has higher values when the dampers are located in the top storey level.

Case 3, 4 &5

The top storey deflection obtained for cases 3, 4 & 5 are tabulated in the Table 6. The top storey deflection obtained for these cases are tabulated in the Table 6. Among these result E31 shows minimum top storey deflection. Fig 12 shows top storey deflection of case 3 configurations. From this, it is evident that, displacement has higher values when the dampers are located in the top storey location. Top storey deflection is reduced when the damper location is moving from the ground floor to the upper floor level.

Fig 9 Top Storey Deflection of Case 3

As per Fig.13 Top storey deflection for the cases E51 and E91 are comparatively lesser than that of other cases

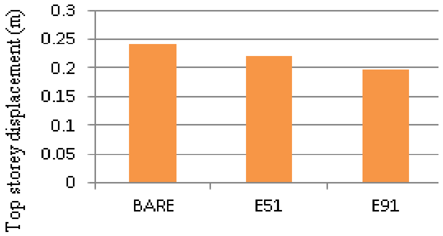

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Fig. 10 Top Storey Deflection of E51 and E91 Patterns

From the above investigation we can say that the patterns E21, E12 and E31 shows lower deflection values for the respective cases. Fig 14 illustrated the deflection produced by these patterns. From the figure it is evident that if the number of dampers increases the seismic deflection control also increases. But after a limit the percentage reduction of buildings are comparable. It indicates, if we increasing the number of damper element the performance increase are verynegligible

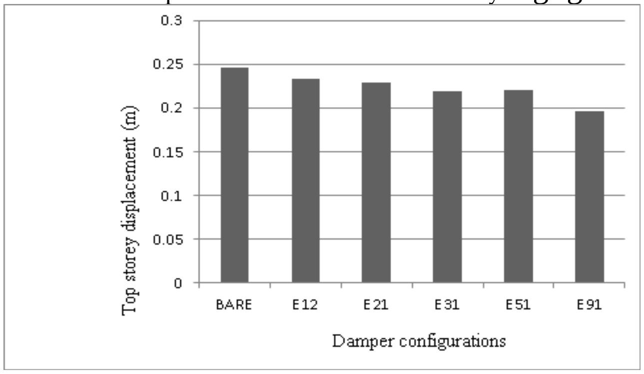

Fig 11 Deflection of E21, E21, E31, E51 & E91 patterns

8. CONCLUSION

This study permitted to study the seismic behaviour of reinforced concrete buildings with and without elasto-plastic viscous damper for Elcentro earthquake loading. The results show that use of passive control device elasto-plastic viscous dampers in buildings generates a very significant reduction of the structural response compared to the bare frame. The main conclusions obtained from the investigation are summarized below Six plan configurations of dampers were selected for the study. Among these configurations P2 configuration performed more efficiently than others. 21% of seismic deflection is minimized by the addition of dampers in P2 configuration. From the time history Elcentro earthquake excitation analysis of twelve vertical configurations, percentage reduction of deflection has minimum value when dampers are located in all the storey levels throughout the height. That is E91 configuration has showed minimum top storey deflection. Percentage reduction of deflection is 21% for E91 configuration. It is also observed that the number of dampers increases the seismic deflection control also increases.

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