

Seismic Response Control of RC Structure using ViscoElastic Dampers

U. P. Vijay^{1*}, P. R. Kannan Rajkumar² and P. T. Ravichandran

¹Engineering Manager, EDRC, L&T Construction, Chennai - 600025, India;vupvijay@Intecc.com

²Department of Civil Engineering, SRM University, Kattankulathur – 603203, Tamil Nadu, India; tokannanonly@gmail.com

Abstract

The study investigates the effect of ViscoElastic (VE) dampers on the overall increase in damping ratio of RCC structure significantly and hence improving the global performance of dynamically sensitive structures. A parametric study is carried out on the proposed Hospital building located at Delhi using VE dampers. The building is chosen such that it is a life line structure and located in a highly seismic prone zone. Finite element analysis was employed using the program ETABS version 9.7.2. In order to show the effectiveness of damper a comparative study on the lateral load resisting behavior between bare(without damper) and damped structures has been studied analytically. The brace type damping mechanism has been modeled as a linear spring and dash-pot in parallel for the ViscoElastic damper. The earthquake events used in this study has been applied as response spectrum acceleration. A number of analyses were carried out to gain a comprehensive understanding of the effectiveness of strategic damper placement in this structure to achieve maximum damping ratio. This study indicates that the dynamic characteristics of ViscoElastic damper have improved the damping ratio additionally by 2% when compared to RCC structure. The effectiveness of adding the ViscoElastic damper reduced the seismic response (drift, displacement, shear and overturning moment) of the structures to about 4 to 20% and control of seismic responses facilitates the optimum design of shear wall without increasing the size of walls by which the net floor area increases about 0.5%.

Keywords: Damping Ratio, Response Spectrum Analysis,ViscoElastic Dampers

1. Introduction

In recent years, structural damage control has taken a central role in seismic design of civil structures. Traditional design relies on the energy dissipation from the yielding of the structural members. However, this leads to severe localized damage in a few regions and causes serviceability issues.

In general, the control of the building response to seismic has been done by increasing the stiffness of the building by increasing the member sizes or by introduction shear walls in excess of what is normally required for strength. In high seismic zones, increasing the member sizes has an additional disadvantage as it increases the mass of the building, leading to higher base shear. In such

a situation, it is usually more optimal solution to increase the damping rather than the building stiffness¹. The purpose of using damper is to increase the damping ratio of the structure which is subjected to lateral loads and decrease the total structural response.

2. Building Profile

The building considered for this study is a Hospital building located at Delhi, consisting of Ground floor +10 floors. Building plan size at ground floor level is 55m X 61.8m and with part terrace at 7,9 floor level. The total height of building is 45,65m with a typical floor to floor height of 4.05m and plinth level of 1.1m above ground level.

*Author for correspondence

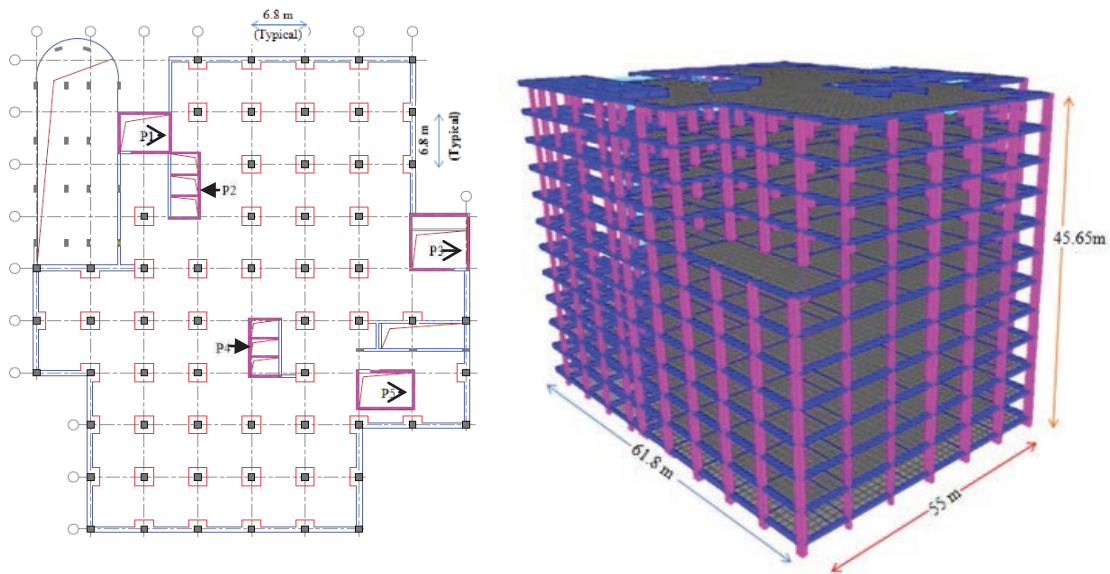


Figure 1. Floor plan of building and 3D analytical model in ETABS.

Columns are spaced at 6.8 x 6.8m center to center and shear wall (Pier Id P1, P2, P3, P4 and P5) located as shown in Figure 1 building plan. Foundation system is considered as footing with Raft slab as per the Geotechnical recommendations. The horizontal structural system comprises of Flat slab with Drops. Beams are provided all along the periphery of the building. Ductile shear walls are provided as lateral load resisting system.

Beams and Columns are modelled as frame elements while RC walls and flat slabs are modelled as shell element. The slab has been considered as a rigid diaphragm

at the respective floor levels. The vertical elements are restrained against rotation and translation at foundation levels.

2.1 Analysis of Structure without Damper

The earthquake ground acceleration for intrinsic damping ratio 5% and seismic values listed in Table 1 is given as a digitized Response-Spectrum curve of Pseudo-Spectral acceleration response versus period as shown in Figure 2 is given in ETABS analytical model. The proposed design methodology is given in Figure 3 for easy reference 2.

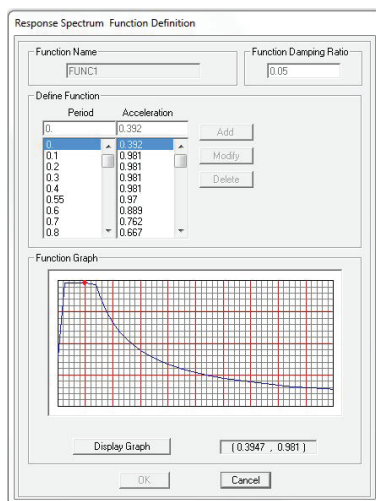


Figure 2. Response Spectrum Function for 5% damping ratio.

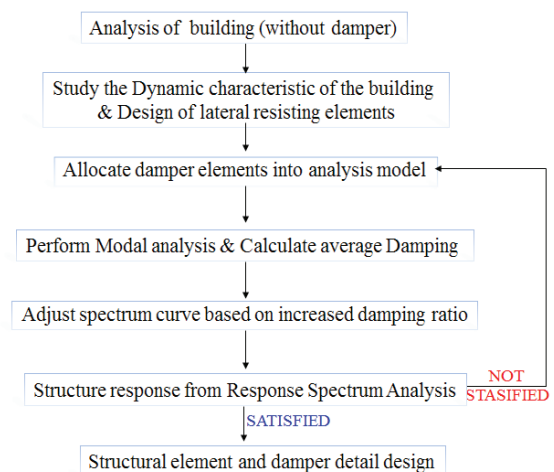


Figure 3. Design Methodology.

Base shear for the structure was obtained both by manual and computational analysis. Static [manual] = 54777kn and Dynamic [from analytical model] = 14415kn. The scale factor obtained = 3.8. Dynamic analysis was performed as per Response spectrum method using ETABS to find seismic response structure.

2.2 Analysis of Structure with Damper

ViscoElastic Damper properties will be computed based on the frequency and shearing deformation values from the analysis results of structure (without damper).

Frequency = $1 / \text{Time period} = 1 / 1.39842 = 0.72\text{Hz}$.
Shearing deformation limit = Inter storey drift $\times$ floor height = 15.8 mm.

Table 1. Seismic Parameters Considered for Analysis

Seismic Zone	IV
Zone factor (Z)	0.24
Soil	Medium soil
Lateral load resisting System	Ordinary moment resisting frame with ductile shear wall
Response reduction factor (R)	4.5
Importance factor (I)	1.5

Brace type dampers are modeled as a Bi-Linear spring and Dash-Pot in parallel (known as the Kelvin Model) as shown in Figure 4. The spring represents stiffness and the Dashpot represents damping³.

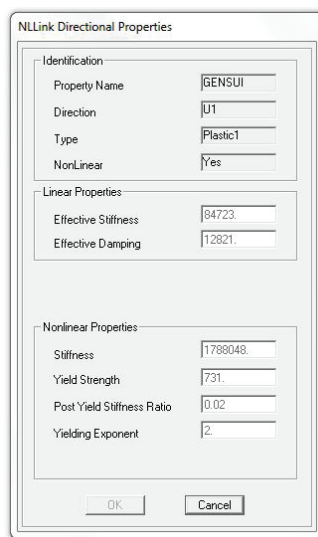


Figure 4. ViscoElastic Damper and Properties Assigned in ETABS Analytical Model.

2.2.1 Optimization of Damper Units

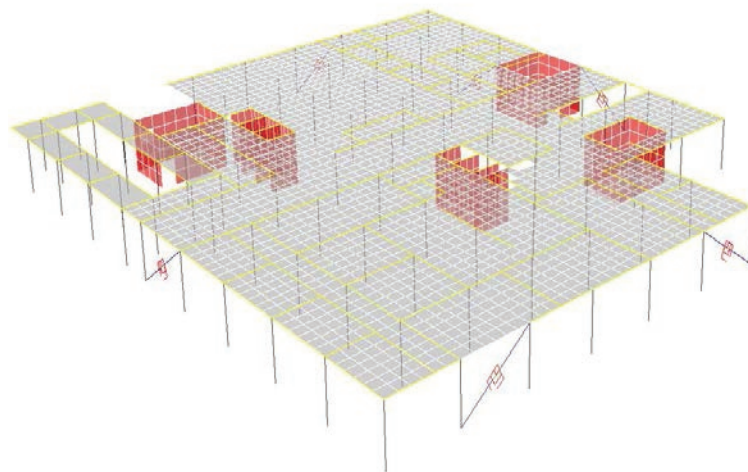
The efficiency of the dampers was studied by varying the damper locations in plan according to the aesthetic and functional requirements. The optimum plan configuration is chosen for the parametric study. The parametric study is based on the following criteria⁴.

- Number of damper units in each Brace.
- Total number of braces in Structure.

Single unit of damper (as shown in Figure 7) is positioned at different location in plan and structural model is analyzed for each case to find the maximum damping ratio. It was found that damper is effective when it is placed at the periphery of building with uniformity in both 'X' and 'Y' direction reducing the distance between the centre of mass and stiffness of floor plan by taking into account of the torsional rigidity. After finalizing the brace locations, the structural model is analyzed for 2,5,10 no of units (as shown in Figure 8) at one brace and results are tabulated in Table 2.

Table 2 Number of units in Single Brace Vs Structural Damping Ratio

No. of units/ Brace	Structural Damping ratio	Reduction in First mode Torsion
2	6.15	10.1%
5	7.10	19.3%
10	7.85	32.2%



There is only marginal increase from 5-10 units, hence 5 units per brace to be the most effective as the increase in cost overcomes the gain in damping. Importantly, functional requirement of concealing within walls is possible for brace element with at most 5 units. Structural models were developed with dampers only at top six floors, only at below 6 floors, Alternate floors and at all floors as show in Figure 5 and results are tabulated in Table 3.

2.2.2 Damping Behavior

Dampers at all floor level gives the 2% increase in damping ratio for which is: 1893–Table 3 recommends 0.9 as multiplying factor to the design horizontal seismic coefficient A_h . The seismic ground acceleration for damping ratio 7% as show in Figure 6 is arrived by keeping all other seismic parameters as in Table 1.

2.2.3 Total Optimized Units in Structure (refer above figures)

- Number of Braces per floor = 6 (3 in X direction & 3 in Y direction).
- Number of Units per brace = 5.
- Number of Brace structure = $11 \times 6 = 66$ no's (330 no of single units).

2.3 Damping Ratio of Structure with and without Damper

In case of RCC structure the damping ratio should be 5% (IS 1893:2002, clause 7.8.2.1) which was verified from the analysis results shown in Table 4. Further ViscoElastic Damper was defined to the structure and the same analysis was done. It's found that the overall weighted average Damping Ratio (DR) based on model participation factor (U_x , U_y) is 7.1% as shown in Table 5. The 2.1%

Table 3. Number of braces in floor wise optimization

No. of floors	Structural Damping ratio	Reduction in first mode torsion
(a) Only at above 6	6.4	7.90%
(b) Only at below 6	6.0	14.50%
(c) Alternate floors	6.3	10.6%
(d) All 11 floors	7.1	19.30%

of damping ratio is increased in the structure due to the introduction of dampers. Increase in damping ratio will reduce the structural response under lateral loads⁵.

In case of RCC structure the damping ratio should be 5% (as per IS 1893:2002, clause 7.8.2.1) which was obtained from the analysis shown in Table 4. Further ViscoElastic Damper was defined to the structure and the same analysis was done. It was found that 2.0% of damping ratio has been increased in the damper structure from Table 5. Increase in damping ratio will reduce the structural response under lateral loads and vibrations⁵. From the analyzed results directly we can compare the maximum story displacement, maximum story drift ratio, base shear and over turning moment.

3. Comparision Graphs of Seismic Response of Structure with and without Damper

The storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the storey height (IS 1893:2002, Cl:7.11.1), i.e. maximum allowable limit is $0.004 \times 4050\text{mm} = 16.2\text{mm}$. It can be seen from Figure 9 the maximum drift (in X direction) at 7th floor level

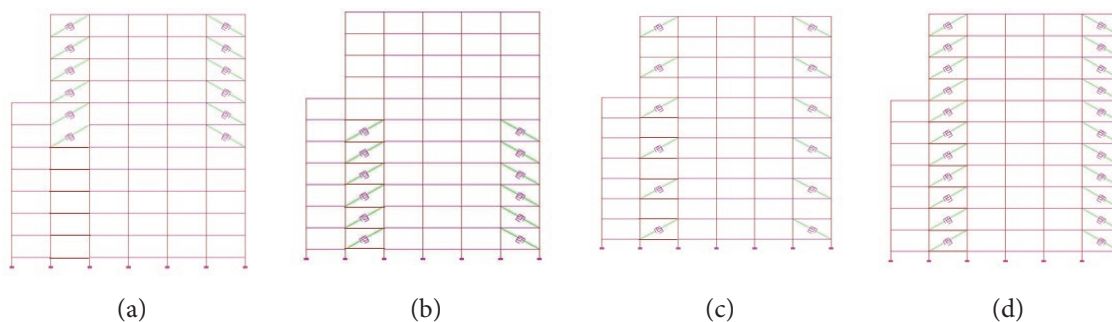


Figure 5. ViscoElastic Damper Location (a) only above 6 floors, (b) only at below 6 floors, (c) alternate floor and (d) at all floors.

Table 4. Damping Ratio Calculation for Structure without Dampers

Bare structure			T=1.3984		
M	U _x	U _y	D.R	X	Y
1	33.90	8.80	0.05	1.69	0.44
2	20.25	42.25	0.05	1.01	2.11
3	10.77	14.30	0.05	0.54	0.71
4	5.11	2.76	0.05	0.26	0.14
5	7.95	9.70	0.05	0.40	0.48
6	4.38	4.95	0.05	0.22	0.25
7	1.88	1.00	0.05	0.09	0.05
8	2.48	3.58	0.05	0.12	0.18
9	1.64	1.40	0.05	0.08	0.07
10	0.92	0.51	0.05	0.05	0.03
11	1.08	1.72	0.05	0.05	0.09
12	0.00	0.00	0.05	0.00	0.00
	90.36	90.96		4.52	4.55
Cumulative Average				ξ_n 5%	ξ_n 5%

Where, U_x, U_y = Modal participating mass ratios, D.R = Damping Ratio, X and Y represents the damping ratio corresponding to model participation factors in X and Y direction of building plan (derived from U_x multiplied by DR).

Table 6. Comparison of Stresses in Shear Wall for Structure with and without Damper

Shear wall	Length (mm)	Thick (mm)	Structure without Damper shear stress (N/mm ²)	Structure with Damper shear stress (N/mm ²)	Reduction
P1	27700	300	4.26	3.93	7.7%
P2	20000	250	3.27	3.11	4.9%
P3	27800	300	3.58	3.34	6.8%
P4	18500	250	3.58	3.41	4.9%
P5	27800	300	3.36	3.13	6.8%

without damper is $0.0039 \times 4050 = 15.8\text{mm}$ which is almost equal to the maximum allowable limit (16.2mm). But for damped structure the maximum storey drift value is $0.0032 \times 4050 = 13\text{mm}$ which is having safety factor of 1.25 as compared to maximum allowable limit.

Overtaking moment results from seismic lateral forces. Torsion from ground motion could be of great concern due to eccentricity in the building layout. These moments are a concern due to the impact that they could potentially have on the foundation system. Figure 10 is a

Table 5. Damping Ratio Calculation for Structure with Dampers

Damped structure			T=1.3525		
M	U _x	U _y	D.R	X	Y
1	38.97	8.36	0.0637	2.48	0.53
2	18.76	42.24	0.0579	1.09	2.45
3	7.39	15.09	0.0834	0.62	1.26
4	5.16	3.24	0.0929	0.48	0.30
5	8.52	8.95	0.0678	0.58	0.61
6	3.64	4.94	0.1103	0.40	0.54
7	1.87	1.11	0.1140	0.21	0.13
8	2.61	3.42	0.0761	0.20	0.26
9	1.49	1.41	0.1108	0.16	0.16
10	0.91	0.56	0.1275	0.12	0.07
11	1.13	1.67	0.0838	0.09	0.14
12	0.00	0.01	0.1233	0.00	0.00
	90.44	90.99		6.43	6.44
Cumulative Average				ξ_n 7.1%	ξ_n 7.1%

summary of the overturning moments of both damped and without damper structure.

It can be seen from Figure 10 the location of braces in floor wise (3 in X direction and 3 in Y direction) gives a satisfactory earthquake response control of a RCC building. It is noted that the reduction in overturning moment is about 4-6% for damped structure.

4. Design of Shear Walls with and without Damper

Shear stresses for the shear walls are computed from the analysis and results are tabulated in Table 6 for both damped and ductile shear wall with OMRF structure. It is confirmed that wall id P1 is exceeding the maximum shear stress limit of 4.0 N/mm^2 as specified in IS 456:200 Table 20. The result of damped structure shows maximum 7.7% reduction controls the stress value within allowable limit to facilitate the design of shear walls without increase the member size.

Increasing the member size has an additional disadvantage as it increase the mass of the building leading to higher seismic loads due to ground acceleration. The addition of ViscoElastic damper absorbs the energy thus reduces the force on lateral resisting elements and with

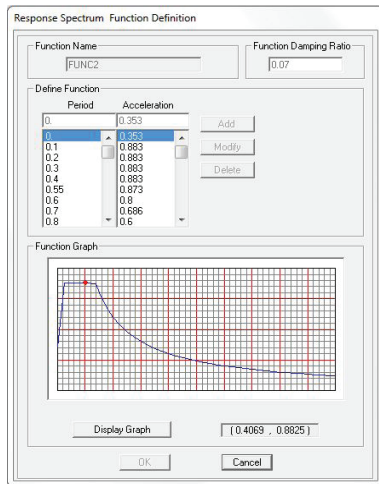


Figure 6. Response Spectrum Function for 7% damping ratio.

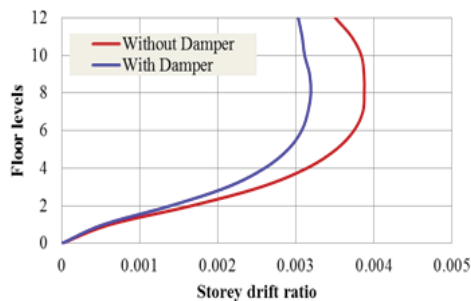


Figure 9. Storey Drift Ratio Comparison.

increased damping. It is possible to reduce the stiffness while at the same time improving the buildings dynamic response.

5. Summary

The Summary of the seismic response of structure with and without dampers provided in Table 7 and it clearly shows the percentage reductions in storey shear, overturning moment, drift ratio and displacement of the structure. The analysis results in Table 7 imply that we can obtain 2% increase in damping ratio of structure controls the RCC building in seismic responses from 14-19% reduction in inter storey drift, roof displacement and 5% decrease in building over turning moment. The first mode time period has also been reduced simultaneously. From the comparisons, it is clear that the ViscoElastically damped structures can be designed conservatively as compared to the conventionally designed structure.



Figure 7. Single Damper Unit 400mm*400mm*t15mm.

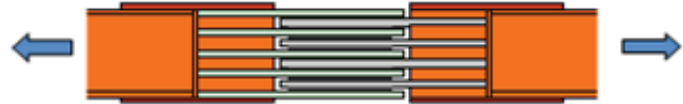


Figure 8. Multiple Damper Units in Single brace.

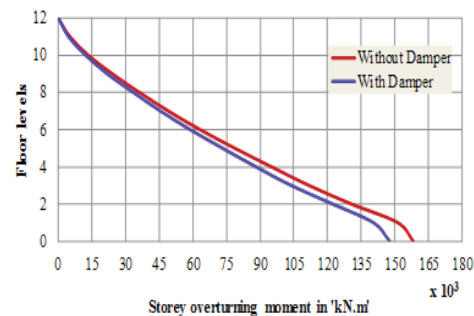


Figure 10. Story Overturning Moments.

Table 7. Comparison of Seismic Response of Structure with and without Damper

Story Response	Structure without Damper	Structure with Damper	Reduction
Max. Base shear (kn)			
X - direction	54928	53742	2.16%
Y-direction	56293	53363	5.20%
Story Overturning moment (kn. m)			
X - direction	1497802	1439162	3.92%
Y-direction	1510323	1409803	6.66%
Max. story drift ratio			
X - direction	3.86E-03	3.10E-03	19.69%
Y-direction	3.50E-03	3.00E-03	14.29%
Max. story Displacement (mm)			
X - direction	148.6	121.27	18.39%
Y-direction	135.4	115.82	14.46%
Time period (sec)	1.3984	1.3525	
Damping ratio	5.00%	7.00%	

6. Conclusions

Summary of results from this study suggest that ViscoElastic dampers are effective in reducing the seismic response of RCC building. A number of analyses were carried out to gain a comprehensive understanding of the effectiveness of the damper placement in this structure to achieve maximum damping ratio. The conclusions of the study are as follows.

- The dynamic characteristics of ViscoElastic damper is improved the damping ratio of RCC structure by additionally 2%.
- The effectiveness of added ViscoElastic dampers is reduced the seismic response (drift, displacement, shear and overturning moment) of the structures about 4-20%.
- Controls of seismic responses facilitate the design of shear wall without increase the size of walls by which the net floor area increases about 0.5%.
- The investigations showed that significant increase in damping ratio of structure can be achieved by strategically placing the dampers.

7. References

1. VSL Damping Solutions for Buildings. <http://www.vsl.com/business-lines/systems-and-technologies/damping-systems-for-buildings>; 2013.
2. IS: 456, Indian Standard Plain and Reinforced Concrete-Code of Practice. Bureau of Indian Standards; 2002; New Delhi.
3. IS:1893, Indian Standard Criteria for Earthquake Resistant Design of Structures. Part- I General Provisions and Building. Bureau of Indian Standards ; 2002; New Delhi.
4. Xu Z-D, Shi C-F. Energy Dissipation Analysis on Real Application by using ViscoElastic Dampers. 14th World Conference on Earthquake Engineering;. 2008; Beijing, China.
5. Chen, YH Chai. Seismic Design of Structures with Supplemental Maxwell Model-Based Brace-Damper Systems. 14th World Conference on Earthquake Engineering;. 2008; Beijing, China.
6. RC Lin, Z Liang, Soong TT, Zhang RH.). An Experimental Study on Seismic Behaviour of ViscoElastic Damped Structures. *Engineering Structures*. 1991;13:75-84.