IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 06, 2016 | ISSN (online): 2321-0613

Control of Structural Vibrations using Friction & Viscoelastic Dampers

Shashank Singh[1] Gargi Danda De[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]B.I.T. Durg

Abstract— An increase in the frequency of occurrence of natural disaster events like Earthquakes has been evident over the past few years. Strong vibration and possible collapse of structures during these events can lead to catastrophic human and economy loss. Damping is one of the most important parameters that limit the response of the structures to these dynamic events. The main aim of this project is to bridge the existing knowledge gaps by undertaking comprehensive investigation of several high and medium-rise structures with different damping devices embedded within cut outs of shear walls. A thorough study will give us an idea about the best suited technique to be employed for reducing the effect of earthquake on the structure. The research aims to address the needs of local industries by carrying out a comprehensive investigation on seismic mitigation of high-rise structures with different damping devices. Nonlinear finite element modeling approach has been used in the current study. For this purpose, we studied the response of modelled frames and commented on the ideal locations of Friction Dampers & VE Dampers. For this Storey Displacements were evaluated.

Key words: SAP, Seismic Dampers, Friction Dampers, Visco-Elastic Dampers, Structural Vibrations

I. INTRODUCTION

The concept of employing structural control to minimize structural vibration was first introduced in the 1970s. It offers attractive opportunities to mitigate damages and loss of serviceability caused by natural hazards such as earthquakes and hurricanes. The control of structural vibrations produced by an earthquake can be done by various means such as modifying rigidities, masses, damping, or shape, and by providing passive or active counter forces.

A. Background Concepts

In earthquake engineering, vibration control is a set of technical means aimed to mitigate seismic impacts in building and non-building structures. All seismic vibration control devices may be classified as passive, active or hybrid.

When ground seismic waves reach up and start to penetrate a base of a building, their energy flow density, due to reflections, reduces dramatically (usually, up to 90%). However, the remaining portions of the incident waves during a major earthquake still bear a huge devastating potential. After the seismic waves enter a superstructure, there is a number of ways to control them in order to sooth their damaging effect and improve the building's seismic performance, for instance:

- To dissipate the wave energy inside a superstructure with properly engineered dampers.
- To disperse the wave energy between a wider range of frequencies.
- To absorb the resonant portions of the whole wave frequencies band with the help of so-called mass dampers.

In seismic structures upgrading, one of the techniques adopted for reducing the lateral forces caused by the earthquake is use of dampers. During an earthquake, high energy is applied to the structure. This energy is applied in two types: kinetic and potential (strain), to structure and it is absorbed or amortized. If structure is free of damping, its vibration will be continuous, but due to the material damping, vibration is reduced. Input energy caused by earthquake to structure is presented in the following equation:

$$E = E_k + E_s + E_n + E_d$$

In this equation, E is earthquake input energy, Ek is kinetic energy, Es is reversible strain energy in the elastic range, Eh is the amount of wasted energy due to inelastic deformation and Ed is the amount of amortized energy by additional damper. In seismic isolation systems, use of energy dissipation systems, allocated a special place to their selves. Damping is possible by using various methods such as the flow of a soft metal, two metal friction on each other and a piston motion within a slimy substance or visco-elastic behavior in materials such rubber-like substances.

II. MODELLING IN SAP2000

Dynamic analysis according to IS: 1893-2002 was selected to obtain the response of the structure under seismic loading.

A. Boundary Conditions

The earthquake events used in this study were recorded as time-history accelerations in the horizontal plane. The acceleration was applied in the X-direction at the base of the structure, as shown below. The support at the base of the structure was restrained against translation in the Y-direction, and rotation about the Z-axis, thereby allowing only the X-direction translation.

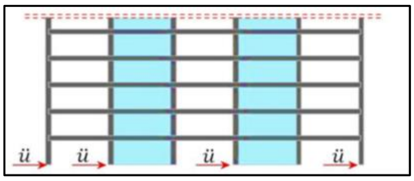


Fig. 1: Model location of applied acceleration

B. Material Properties

Concrete material properties were chosen for the models since many multi-storey buildings in India are constructed by using reinforced concrete. The concrete had a compressive strength, f'_c of 35 N/mm^2, Young's modulus, E_c of 30,000 N/mm^2, which reflects an assessment assuming predominantly elastic response with little cracking, Poisson's ratio, υ of 0.2, and density, ρ of 2500 kg/m^3. No internal damping was considered for the concrete since it was assumed small in relation to the damping provided by the damping devices. Structural steel was used to model friction dampers with yield strength, f_y of 415 N/mm^2, and Young's modulus, E_s of 207,000 N/mm^2, Poisson's ratio υ of 0.3 and density, ρ of 7800 kg/m^3.

C. Nonlinear Concrete Material Modeling

One of the methods to model nonlinear concrete material modeling is multi-cracking concrete with crushing model. This model stimulates the nonlinear behaviour of concrete in both compression and tension at the same time. Therefore, the yield function consists of the two main parameters which are the tension softening of concrete and compression crushing. As a result, this model is suitable cracking and crushing failure at the same time. The typical behaviour of the tension softening effect and concrete crushing is shown as below:

D. Nonlinear Steel Material Modeling

To choose a suitable model, we have to know the behaviour of the steel. The model must able to stimulate the behaviour of the steel. Here we choose stress potential method. The stress potential method able to simulate the yield behaviour in all direction of stress space required under multiaxial stress. Besides that, it could also show the hardening properties of steel in terms of hardening gradient and effective plastic strain.

E. Damper Placement in 16 storey Frame Structures

One of the main aims of this study was to investigate the efficiency of energy dissipating dampers in vibration control for variety of placements under different earthquake loads. For this purpose six different damper placements were used to study the influence of location on the seismic response of these models.

These models were designated by F1, F3, F6, F9, F12 and F15 for Friction damper placements and by V1, V3, V6, V9, V12 and V15 for Viscous damper placements within the models. As can be seen in the following figures, the designating numbers correspond to location of the storey at which dampers were placed. The undamped structure was also analyzed in order to compare results.

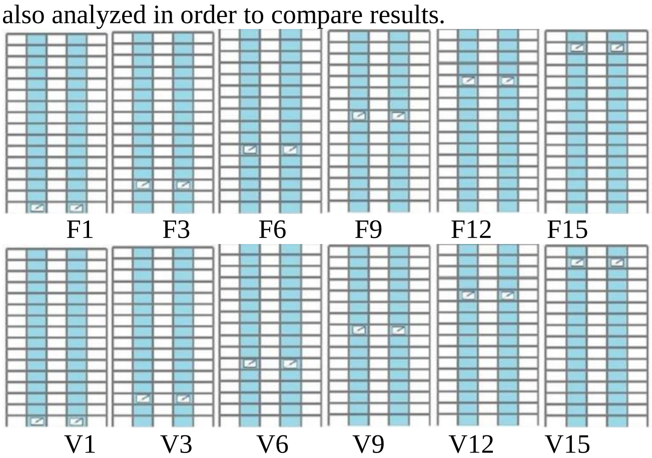


Fig. 2: Placement of dampers within 16 storey frame structures

The following assumptions were made before the start of the modeling procedure so as to maintain similar conditions for all the three models:

- Only the main block of the building is considered. The staircases are not considered in the design procedure. Plan size is 4 m x 4 m with a floor height of 4 m.
- The building is to be used for exhibitions and so no interior walls are provided.
- Only external walls 230 mm thick with 10 mm plaster on each side are to be provided. However for more accurate results, only the framing members are considered and walls are neglected.
- At ground floor, slabs are not provided and the floor is resting directly on the ground.
- The beams are resting centrally on the columns so as to avoid the conditions of eccentricity.
- The footings are not designed. Supports are assigned in the form of fixed supports.
- Sizes of the members are as follows: (All dimensions are in mm)

Property	**Material**	**Values**
Columns	Concrete - M40	700 mm x 700 mm
Beams	Concrete - M40	500 mm x 300 mm
Slabs	Concrete - M40	20 mm

Table 1: Property

- Seismic loads are considered in the horizontal direction only and the vertical direction is assumed to be insignificant.
- The buildings are to be designed for the following conditions:

Live load = 4 KN/m^2 (Typical floor); 1.5 KN/m^2 (Roof)
Location = Seismic Zone V (Not designed for Wind Loads as EQ loads are greater)
Soil type = Soft; as per IS-1893(Part 1):2002
Floors = G+15 (Floor height = 4 m)

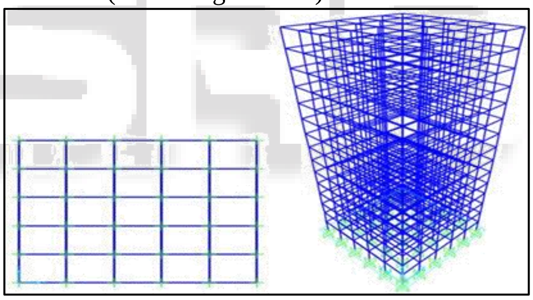


Fig. 3: Modelled Buildings of 16 storey in SAP2000

F. Structural Model with Friction Damper – Diagonal Configuration

Details of the diagonal friction damper located within frame model can be seen in the following figure where a 3.5 m wide by 3.5 m high wall section was cut out and replaced by the damper. This damper was modelled as a pair of diagonal tubes each with a thickness of 50 mm, and with one tube placed within the other.

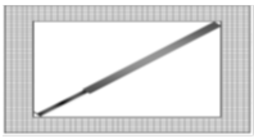


Fig. 4: Structural details of Diagonal Friction Dampers

The response of this model as well as all others was investigated under the appropriate earthquake excitations which will be described later. It's worth mentioning that the connection between FR damper and the frame is modelled by a pinned joint element with elasto-plastic behavior and special interface elements with friction-sliding properties have been used for modeling the friction behavior between the tubes.

G. Structural Models with VE Damper–Diagonal Configuration

The concrete frame was modelled using the same FE mesh, material properties and dimensions as in the previous models. Detail of the diagonal VE damper located within the cut out of the frame can be seen in Fig. 27. The properties of the damper for 16-storeys models were at first calculated as K_d = 10 × 106 N/m and C_d = 63 × 106 Ns/m based on double layer damper in parallel with dimensions of 1,850 mm by 300 mm by 10 mm and the values G'= 900,000 Pa and G"= 300,000 Pa. These moduli were calculated using the loading frequency f = 0.718 Hz, which corresponded to the fundamental frequency of this structure model.

1) Note

The values of K_d and C_d are taken from "Seismic design with supplemental energy dissipation devices" published by Earthquake Engineering Research Institute,145-156(2003), presented by Robert. D. Hanson, TSU T. Soong.

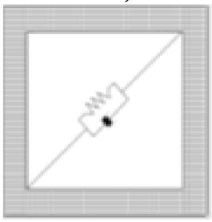


Fig. 5: Structural details of Diagonal VE Dampers

H. Loadings & Load Combinations

The earthquake records, which were selected to investigate the dynamic response of the models, are selected as per IS:1893-2002. Many load combinations were considered during the analysis of the model. But for asserting the simplest yet reliable method for analysis, the combined action of DL, LL & EQ forces are considered i.e. 1.2 Dead + 1.2 Live + 1.2 EQ.

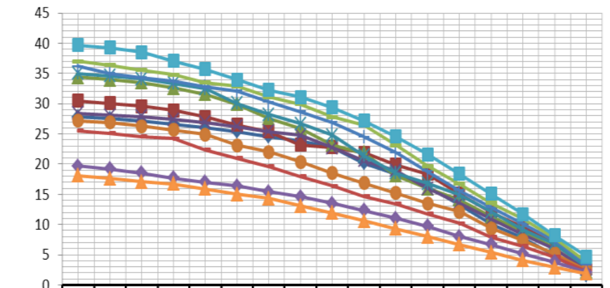
III. RESULTS & DISCUSSIONS

The results from the finite element analysis of high-rise structures of 16 storeys are presented in this section. The damping systems were installed within cut outs of shear wall at different damper placements. Seismic analyses were carried out with one type of damper at one placement at a time. Efficiency of these damping systems was investigated under earthquake excitations in accordance to IS:1983-2002. The values of Storey Displacements at each floor for all the different models was calculated by observing the individual displacements of all the nodes at a particular storey and calculating its average value. In our models, there were 36 nodes or junctions at each storey at which individual displacements was calculated using SAP2000 and finally the storey displacement at that particular floor was calculated by taking the average of those 36 individual displacement values.

Story	F1	V1	F3	V3	F6	V6	F9	V9	F12	V12	F15	V15
Sixteen	27.8	30.5	34.4	28.4	35.0	27.2	36.2	25.5	37.0	19.7	39.7	18.1
Fifteen	27.5	30.1	34.0	28.1	34.6	26.9	35.0	25.1	36.4	19.2	39.3	17.6
Fourteen	27.1	29.6	33.5	27.9	34.1	26.3	34.3	24.6	35.6	18.5	38.5	17.1
Thirteen	26.6	28.9	32.6	27.4	33.4	25.7	33.7	24.2	34.8	17.7	37.1	16.7
Twelve	26.0	27.8	31.6	26.9	32.5	24.9	32.8	22.4	33.5	17.0	35.7	15.9
Eleven	25.4	26.5	29.9	26.2	30.1	23.1	32.1	21.0	32.9	16.4	34.0	15.0
Ten	24.6	25.4	27.6	25.4	28.2	22.0	30.3	19.6	31.1	15.4	32.3	14.3
Nine	23.9	23.2	25.9	24.8	26.7	20.4	28.7	18.0	29.9	14.6	31.1	13.1
Eight	22.8	22.8	23.2	22.7	24.8	18.5	26.9	16.4	27.8	13.5	29.4	11.9
Seven	20.2	21.9	21.8	20.6	21.4	16.9	24.5	14.7	26.4	12.3	27.2	10.6
Six	18.4	19.9	18.1	18.9	18.5	15.2	21.9	13.4	23.1	11.0	24.6	9.3
Five	16.3	18.4	16.0	16.0	16.8	13.5	18.8	11.8	19.7	9.7	21.6	8.0
Four	13.2	15.1	14.1	13.6	14.9	12.1	15.6	10.2	16.7	8.0	18.4	6.7
Third	10.1	12.0	11.3	10.9	12.1	9.4	12.8	7.9	13.6	6.7	15.1	5.4
Second	7.7	9.6	8.9	8.3	9.2	7.4	10.1	6.4	10.9	5.2	11.7	4.1
First	4.9	6.8	6.1	6.0	6.8	5.2	7.3	4.6	7.7	3.8	8.2	2.9
Ground	1.6	2.9	2.2	2.6	2.9	2.4	3.3	2.3	3.8	2.1	4.7	1.9

Table 1: Maximum Storey Displacements for different Models (in mm)

The above table and figure shows the values of Storey Displacements for different models added with Friction & VE Dampers. The number corresponding to 'F' & 'V' indicates the floor at which the dampers are placed. It is clear from the above table that the values of Storey Displacements are minimum in case of F1 i.e. when the friction dampers are placed near the ground floor of the 16 storey structure. This is closely followed by V15 i.e. when the VE dampers are placed near the top floor of the 16 storey structure. It can be thus concluded that VE dampers are more effective when they are placed farther from the ground and Friction dampers are more effective when they are placed nearer to the ground.



	Sixteen	Fifteen	Fourteen	Thirteen	Twelve	Eleven	Ten	Nine	Eight	Seven	Six	Five	Four	Third	Second	First	Ground
F1	27.8	27.5	27.1	26.6	26	25.4	24.6	23.9	22.8	20.2	18.4	16.3	13.2	10.1	7.7	4.9	1.6
V1	30.5	30.1	29.6	28.9	27.8	26.5	25.4	23.2	22.8	21.9	19.9	18.4	15.1	12	9.6	6.8	2.9
F3	34.4	34	33.5	32.6	31.6	29.9	27.6	25.9	23.2	21.8	18.1	16	14.1	11.3	8.9	6.1	2.2
V3	28.4	28.1	27.9	27.4	26.9	26.2	25.4	24.8	22.7	20.6	18.9	16	13.6	10.9	8.3	6	2.6
F6	35	34.6	34.1	33.4	32.5	30.1	28.2	26.7	24.8	21.4	18.5	16.8	14.9	12.1	9.2	6.8	2.9
V6	27.2	26.9	26.3	25.7	24.9	23.1	22	20.4	18.5	16.9	15.2	13.5	12.1	9.4	7.4	5.2	2.4
F9	36.2	35	34.3	33.7	32.8	32.1	30.3	28.7	26.9	24.5	21.9	18.8	15.6	12.8	10.1	7.3	3.3
V9	25.5	25.1	24.6	24.2	22.4	21	19.6	18	16.4	14.7	13.4	11.8	10.2	7.9	6.4	4.6	2.3
F12	37	36.4	35.6	34.8	33.5	32.9	31.1	29.9	27.8	26.4	23.1	19.7	16.7	13.6	10.9	7.7	3.8
V12	19.7	19.2	18.5	17.7	17	16.4	15.4	14.6	13.5	12.3	11	9.7	8	6.7	5.2	3.8	2.1
F15	39.7	39.3	38.5	37.1	35.7	34	32.3	31.1	29.4	27.2	24.6	21.6	18.4	15.1	11.7	8.2	4.7
V15	18.1	17.6	17.1	16.7	15.9	15	14.3	13.1	11.9	10.6	9.3	8	6.7	5.4	4.1	2.9	1.9

Fig. 6: Maximum Storey Displacements (in mm) for Different Models

IV. Conclusions

A strategy for protecting buildings from earthquakes is to limit the tip deflection, which provides an overall assessment of the seismic response of the structure. Different building structures require different damping systems for the best results. However, the present study demonstrated that some trends common for all investigated structures can be observed. Visco-Elastic (VE) dampers or Viscous Dampers are most effective when placed in the higher storeys.

- Friction dampers are most effective when placed close to regions of maximum inter-storey drift i.e. near the lower stories.
- Diagonal Viscous dampers experienced highest sensitivity to placement and variations in seismic excitations. These dampers achieved the most significant performances under earthquakes, which caused high deflection resistance.
- In case of the model G+15 storey structures, VE Dampers showed better overall efficiency when compared to Friction Dampers.
- The values of Average Storey Displacements were greatly reduced by the addition of Friction & Viscous Damping mechanisms.

This study has shown that it is possible to achieve seismic mitigation, under all earthquake excitations, for all the structures considered in this study, by using appropriate damper types suitably located within the structure. In order to control the vibration response of the medium and high rise structures during earthquake events, passive dampers as energy absorption devices are mostly used. There have been several studies undertaken to develop a method, which optimizes the use of energy dissipating dampers in vibration control of buildings under earthquake loads.

Reference

[1] Robert. D. Hanson, TSU T. Soong; "Seismic design with supplemental energy dissipation devices" published by Earthquake Engineering Research Institute,145-156(2003)

[2] Trevor E Kelly Holmes Consulting Group, Damper Design Guidelines, (2001)

[3] Journal of the seismic rehabilitation of existing buildings 360-2006 instructions "Department of Engineering Management and Planning",(2006)

[4] Warn, G. P. and Whittaker, A. S. "Performance estimates in seismically isolated bridges", Engineering Structures, Vol.26, pp. 1261-1278(2004).

[5] Naeim, F. & Kelly, J. M, John Wiley and sons. "Design of seismic isolated structures from theory to practice",(1999).

[6] American Association of State Highway Officials "Guide Specifications for Seismic Isolation Design", Washington, D.C., American Association of State Highway Officials , (1999).

[7] Hwang, J.S. and Sheng, L.H. "Equivalent elastic seismic analysis of base-isolated bridges with lead-rubber bearings", Engineering Structures, Vol.16, No.3, pp. 201-209(1994).

[8] Hwang, J.S. and Chiou, J.M. "Equivalent linear model of lead-rubber seismic isolation bearings", Engineering Structures, Vol. 18, No.7, pp. 528-536(1996).

[9] Hwang, J.S., Chiou, J.M., Sheng, L.H. and Gates, J.H. "A refined model for base isolated bridges with bi-linear hysteretic bearings", Earthquake Spectra, Vol.12, No.2, pp. 245-273(1996).

[10] Ghobarah, A. and Ali, H.M. "Seismic performance of highway bridges", Engineering Structures, Vol.10, No.3, pp. 157-166(1988).

[11] Pagnini, L.C. and Solari, G. "Stochastic analysis of the linear equivalent response of bridge piers with aseismic devices", Earthquake Engineering and Structural Dynamics, Vol.28, No.5, pp. 543-560(1999).

[12] Saiidi, M., Maragakis, E. and Griffin, G. "Effect of base isolation on seismic response of multi-column bridges", Structural Engineering Mechanics, Vol.8, No.4, pp. 411-419(1999).

[13] Chaudhary, M.T.A., Abe, M., Fujino, Y. and Yoshida, J. "Performance evaluation of baseisolated Yama-age Bridge with high damping rubber bearings using recorded seismic data", Engineering Structures, Vol.23, No.8, pp. 902-910(2001).

[14] Jangid, R.S. "Seismic response of isolated bridges", Bridge Engineering, Vol.9, No.2, pp. 156- 166(2004).

[15] Ryan, K. L. and Chopra, A. K. "Estimation of seismic demands on isolators based on nonlinear analysis", Structural Engineering, Vol.130, No.3, pp. 392-402(2004).