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SEISMIC ANALYSIS OF BUILDING USING TWO TYPES OF PASSIVE ENERGY DISSIPATION DEVICES

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ABSTRACT : *Post earthquake observations revealed many deficiencies in structures to adapt to seismic engineering practices and lack of seismic resistant features led to collapse and other catastrophic events. Hence to improve the seismic response of buildings in earthquake prone areas, passive energy absorbing devices are used. Here a 6 storeyed regular building is proposed to be analysed using SAP2000 v14 with viscous damper (VFD), with Tuned Mass Dampers (TMD) and without any damping device. Tuned Mass Dampers with varying mass ratios of 2%, 3% and 5% was applied. Time History Analysis was carried out by applying the Bhuj (2001) intensity of earthquake. Similarly, VFDs with damping exponent values of 0.5 and 0.75 of required stiffnesses was input to the structure and analysis was done. Non-Linear Time History Analysis (NLTHA) was carried out. A comparative study was done.*

Keywords *– Bhuj Ground Motion, Non Linear Time History Analysis, SAP2000 v14, Tuned Mass Damper, Viscous Fluid Damper*

1. Introduction

An earthquake is a natural phenomenon associated with violent shaking of the ground. They are vibrations of the earth's surface caused by sudden movements of earth crust mostly due to tectonic movements. Since earthquake forces are random in nature and unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. Earthquake loads are to be carefully modelled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. In this context Non-linear Time History Analysis (NLTHA) which is a time step integration method shall be looked upon as an alternative for the orthodox analysis procedures. In this study the seismic behaviour of a RC irregular and regular buildings with viscous dampers, tuned mass dampers (provided at the top) and without any damping device are planned to be evaluated using NLTHA. By using dampers, historical structures, bridges, military structures etc. can be protected from severe damages.

2. Research Significance

Reinforced concrete structures having tall heights in earthquake prone areas cannot withstand large displacements on its own. To resist the drifts and large displacements in buildings which may cause damage to buildings and death to humans, can be resisted to a large extend by using base isolation techniques, or by damping techniques. Many studies have been carried out by researchers on the use of dampers on buildings to reduce the seismic effect. Sadek, *et al.*, (1997), [1] suggested a method of estimating the parameters of tuned mass dampers for seismic applications. Dethariya, *et al.*, (2011), [2] studied the non-linear time history analysis of a nine storied building frame with and without braced type viscous damper placed at different storey level. Thakur, *et al.*, (2012), [3] conducted the analysis of a six-storied building with rectangular shape incorporated with Tuned Mass Dampers.

The main objectives of this study are:

- To find the seismic response (storey drift, story displacement and base shear) of a regular reinforced concrete building without any damping device using SAP2000 v14.
- To find the seismic response of a regular reinforced concrete building with viscous fluid damper (VFD) using SAP2000 v14.
- To find the seismic response of a regular reinforced concrete building with Tuned Mass Damper (TMD) using SAP2000 v14.

- To compare the seismic response of building in terms of storey drift, storey displacement and base shear due to inclusion and exclusion of dampers.

3. Present investigation

The case study building is planned to be constructed at Gujarat (Bhuj- zone V) seismic zone. This region was chosen for the study because several major faults crisscross this region. The structural configuration of the regular (rectangular) building is shown below.

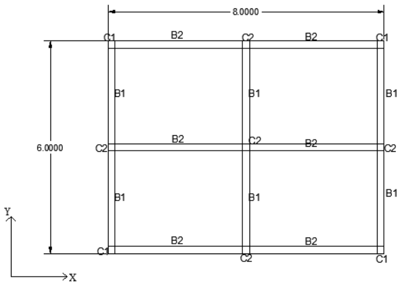


Fig.1 Plan of regular (rectangular) building

Table 1 Column, Beam and Slab dimensions

SI No.	Dimensions
1	C1 – 230 × 230 mm
2	C2 – 230 × 400 mm
3	B1 – 230 × 400 mm
4	B2 – 230 × 400 mm
5	Slab- 100 mm thick

The building has 6 storeys with each storey height of 3m.

4. Modelling and Analysis

In this study, the SAP2000 v14 software was used for nonlinear structural analysis. The loading diagram of the 6 storey rectangular building is shown below in Fig.2.

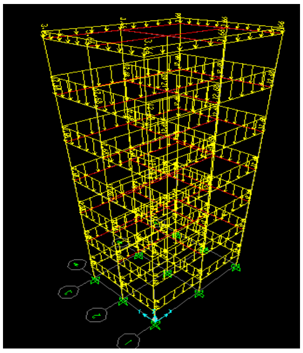


Fig.2 Loading diagram of regular building

The modal mass of the building was manually calculated. The modal mass of the regular (rectangular) building was obtained as 590.64tons.

4.1 TMD parameters

The optimum parameters of TMD (Tuned Mass Damper) were taken from the studies conducted by *Sadek, F (1997)*. He proposed that effective mass ratio should be used for calculating optimum parameters of TMD. The effective mass ratio (μ) and optimum frequency ratio/ tuning ratio (f_{opt}), is given by the following equations [1]:

$$\mu = \frac{m}{M_1} \qquad (1)$$

$$f_{opt} = \frac{1}{(1+\mu\varphi)}\left[1-\beta\sqrt{\frac{\mu\varphi}{1+\mu\varphi}}\right] \quad (2)$$

$$f_{opt} = \frac{\omega_d}{\omega} \quad (3)$$

where: m = mass of TMD; M_1 = modal mass of the structure; μ = effective mass ratio; φ = amplitude of first mode; β = Damping ratio of main building (critical damping of structure usually 5%);
ω_d = First natural frequency of TMD; ω = First natural frequency of the building.
The basic building characteristics to find optimum TMD parameters are shown below. The fundamental frequency and amplitude of first mode are obtained after analysis using SAP2000 v14.

Table 2 Basic building characteristics to find optimum TMD parameters

System	**Fundamental frequency (Hz)**	**Modal Mass (t)**	**Amplitude of Ist mode**
Rectangular building	1.0272	590.64	0.1079

Then the optimum parameters can be calculated using the equations (1), (2) and (3).

Table 3 Optimum parameters of TMD for regular building

Mass ratio (μ)	**Tuning ratio (f_{opt})**	**Mass of TMD, m (t)**	**First natural frequency of TMD, ω_d (Hz)**
0.02	0.9955	11.813	1.023
0.03	0.9939	17.719	1.021
0.05	0.9910	29.532	1.018

Once the optimum parameters of TMD are known, the size of columns, beams and slab thickness of TMD can be calculated by trial and error analysis. Details of TMD are given below.

Table 4 Details of TMD for regular building

Mass ratio (%)	**Column size**		**Beam size**		**Slab thickness (mm)**	**Total mass (t)**	**Actual mass (%)**
	C1	C2	B1	B2			
2	66×120	85.7×140	100×140	120×150	76.5	11.802	1.998
3	96.6×130	88×120	140×200	160×200	111.8	17.705	2.998
5	94×160	100×180	180×200	160×200	202.5	29.532	4.999

4.2 Viscous Fluid Damper (VFD) parameters

The important factors affecting the performance of any damper applied to a building are the damping coefficient (C), damping exponent (n) and the stiffness of the damper (k_d). By knowing the mass of the building (m) and the first natural frequency (f) of the building, the stiffness of the building (k) can be calculated as shown below:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (4)$$

The output force F_D of the fluid viscous damper [4] may be expressed as:

$$F_D = C\,V^n \quad (5)$$

where: C is damping coefficient, n is damping exponent, V is relative velocity between ends of the device.
Generally for tall buildings the n values are taken in the range of 0.5 to 0.8 [4]. In present study the values of n are taken as 0.5 and 0.75 respectively.
Also the critical damping C_c of the structure can then be calculated as:

$$C_c = 2\sqrt{mk} \tag{6}$$

Also, Damping ratio, $\zeta = \frac{C}{C_c}$ (7)

where: C_c is the critical damping of the structure, m is the mass of the building, k is the stiffness of the building, ζ is the damping ratio (usually taken as 0.5 for experiments with building models [4])

For X and Y directions based on the trail analysis, the stiffness k_d values were found out for the damper in order to satisfy the storey drift limitation criterion of values below 0.004times the storey height as given in *IS 1893 (Part I): 2002*[5]

Based on above equations and trial analyses the VFD properties for regular building along X and Y directions were obtained as shown in the Table 5 below.

Table 5 VFD properties for regular building

SI No:	**Mass of Building (kNs^2/m)**	**Damping Exponent (*n*)**	**Damping Coefficient, *C* (kNs/m)**	**X-direction**	**Y-direction**
				Stiffness of damper, k_d (kN/m)	Stiffness of damper, k_d (kN/m)
1	590.64	0.5	3812	140000	190000
2	590.64	0.75	3812	110000	180000

Then Time History Analysis was carried out for bare regular building frame, buildings with TMDs and VFDs.

5. Results and Discussions

From Table 6 and Table 7 shown below, it is seen that the storey drift values are slightly high for the top floor while using TMD's of 2%, 3% and 5% for X-direction excitation and Y-direction excitation respectively. In the case of rectangular building the storey height is 3m. According to the storey drift limitation given in *IS 1893 (Part I): 2002* [5] each storey drifts must be limited to 0.004 times the storey height, which is 1.2%. From the Table6 and Table7 it is seen that by using VFDs with n values 0.5 and 0.75, the story drift criterion is achieved. The same criterion could not be achieved by using TMDs as they are designed for the fundamental frequency of the building and not for the earthquake excitation.

Table 6 Maximum storey drift of regular building for Bhuj X-excitation (in %)

Floor	**Bare Building frame**	**Building with TMD**			**Building with VFD**	
		2% TMD	3% TMD	5% TMD	n = 0.5	n = 0.75
Ground-First	10.93	9.83	7.22	8.44	1.14	1.14
First-Second	11.33	10.34	7.66	9	1.18	1.19
Second-Third	10.21	9.61	7.25	8.53	1.06	1.06
Third-Fourth	8.42	8.35	6.48	7.68	0.88	0.88
Fourth-Fifth	6.1	6.67	5.45	6.5	0.64	0.64
Fifth-Sixth	3.54	4.76	4.18	5.1	0.37	0.37

Table 7 Maximum storey drift of regular building for Bhuj Y-excitation (in %)

Floor	**Bare Building frame**	**Building with TMD**			**Building with VFD**	
		2% TMD	3% TMD	5% TMD	n = 0.5	n = 0.75

Ground-First	12.62	12.69	11.36	9.25	0.89	1.19
First-Second	12.47	12.5	11.25	9.24	1.01	1.2
Second-Third	11.63	11.37	10.33	8.6	1.14	1.15
Third-Fourth	10.23	9.6	8.88	7.59	1.18	1.02
Fourth-Fifth	7.92	7.33	6.99	6.29	1.01	0.89
Fifth-Sixth	4.73	4.75	5.03	4.85	0.62	0.57

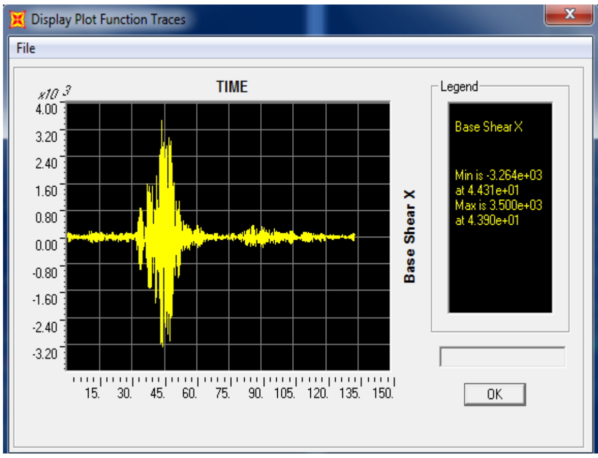
Table 8 Top Storey Displacement reduction using TMDs for X and Y excitations

EQ	**Maximum displacement at top storey**				**% reduction in top storey**		
	Bare Frame	2% TMD	3% TMD	5% TMD	2% TMD	3% TMD	5% TMD
Bhuj-X	524.1	512.4	394.7	467	2.23	24.69	10.89
Bhuj-Y	615.5	602	555.9	472.5	2.19	9.68	23.23

Table 9 Top Storey Displacement reduction using VFDs for X and Y excitations

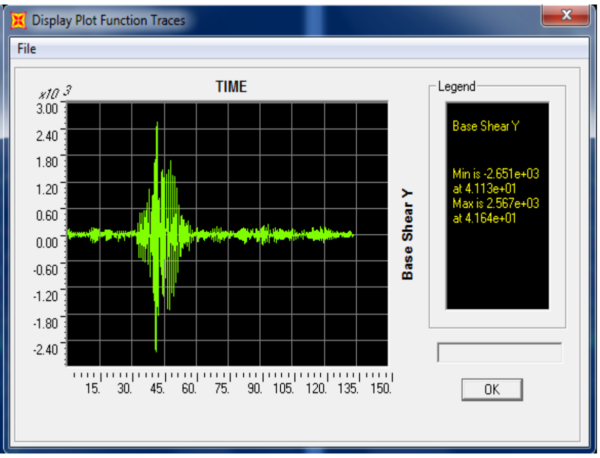
EQ	**Maximum displacement at top storey**			**% reduction in top storey**	
	Bare Frame	VFD		VFD	
		n = 0.5	n = 0.75	n = 0.5	n = 0.75
Bhuj-X	524.1	54.7	54.8	89.56	89.54
Bhuj-Y	615.5	59.8	62	90.28	89.93

Also the Top storey displacement values as well as the top storey displacement reductions were obtained after analysis as shown in Table 8 and Table 9 above.



Base Shear X

Min is -3.264e+03
at 4.431e+01
Max is 3.500e+03
at 4.390e+01



Base Shear Y

Min is -2.651e+03
at 4.113e+01
Max is 2.567e+03
at 4.164e+01

(a) (b)

Fig.3 Base Shear for regular building (a) along X direction, (b) along Y direction

Then, from base shear plots that were obtained after analysis for bare regular building frame, buildings with TMD & VFD, the data is tabulated and are shown in Table 10 and Table 11 for both directions of excitation.

Table 10 Base shear of rectangular building with TMDs for X and Y excitations

Time History	**Base shear (kN)**						
	Bare Building frame	Building with TMD			Percentage reduction		
		2% TMD	3% TMD	5% TMD	2% TMD	3% TMD	5% TMD
Bhuj X	3500	3118	2279	2667	10.91	34.89	23.8
Bhuj Y	2651	2669	2383	1937	-6.79	10.11	26.93

Table 11 Base shear of rectangular building with VFDs for X and Y excitations

Time History	**Base shear (kN)**				
	Bare Building frame	Building with VFD		Percentage reduction	
		n = 0.5	n = 0.75	n = 0.5	n = 0.75
Bhuj X	3500	364.1	364.9	89.6	89.57
Bhuj Y	2651	183.3	249.2	93.09	90.6

6. Conclusions

After the analysis of regular building with Tuned Mass Dampers, with Viscous Fluid Dampers and without any damping device, the following inferences can be drawn:

- It has been found that the TMDs and VFDs can be successfully used to control vibration of the structure.
- For the regular building frame, 3% TMD is found to effectively reduce base shear by about 10-35% and top storey displacement by about 10-25% (amongst 2%, 3% and 5% TMD's).
- By using VFDs of particular stiffness value it is possible to reduce the drift of each floor to the limiting criteria i.e.to 1.2% in case of regular building frame.
- For the regular building, VFD with damping exponent (n) value 0.5 is found to be better than VFD with damping exponent value 0.75. VFD with damping exponent value 0.5 is found to be effective in reducing the top storey displacement by about 90% and base shear by about 89-93%.
- TMDs are easy to construct and implement on top of buildings compared to implementation and placing of VFDs of particular stiffness on buildings.
- From analysis it can be seen that it is necessary to properly implement and construct a damper in any high rise building situated in earthquake prone areas.

Finally, recommendations for the future research in the field of applying TMD is on an experimental model using shaking table to validate the results of using TMD in reducing both displacements and shear forces in the high rise buildings. TMDs need to be designed for each earthquake ground motion data and not for the fundamental frequency of the building. Also it is necessary to formulate a mathematical equation for the VFD, so that standard VFDs can be used efficiently to reduce the overall displacement of the building.

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