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Seismic Analysis of Multistoried Building with TMD (Tuned Mass Damper)

Thakur V.M.[1], Pachpor P.D.[2]

1- Assistant Professor, Civil Engineering Dept., Shri Ramdeobaba College of Engineering and Management, Nagpur, India.

2- Associate Professor, Civil Engineering Dept., Shri Ramdeobaba College of Engineering and Management, Nagpur, India.

Abstract

Tuned Mass Damper (TMD) is a passive control device which absorbs energy & reduces response of vibration. It is attached to vibratory system. TMD is considered to have same damping ratio as that of main structure. The effect of TMD with optimum parameters (frequency ratio & mass ration) given by Sadek, F (1997), is studied. In this paper TMD is used as soft story which is considered to be made up of RCC, constructed at the top of the building. A six storied building with rectangular shape is considered for analysis. Analysis is done by FE software SAP 2000 by using direct integration approach. TMDs with percentage masses 2% & 3% are considered. Three different recorded time histories of past EQ. are used for the analysis. Comparison is done between the buildings with TMD and without TMD.

Keywords: Dynamic responses, Free vibration characteristics, Optimum parameters, TMD.

1.Introduction

Fast urbanization has led to construction of a large number of multistoried buildings. Seismic safety of these building is of importance. Efforts have led to development of techniques like base isolation, active control and passive control devices.

Base isolation technique is shown to be quite effective and it requires insertion of isolation device at the foundation level, which may require constant maintenance. Active control techniques turn out to be quite costly for buildings, as they need continuous power supply. In developing countries like India, such control devices can become popular only if they are easy to construct. Their design method is compatible with present practices and shall not require costly maintenance.

With the aim of developing such a simple control device, some studies have been undertaken in last couple of years. In these studies a simple type of Tuned Mass Damper (TMD) has been proposed. A tuned mass damper (TMD) is a passive energy dissipation device, consists of a mass, spring, and a damper, connected to the structure in order to reduce the dynamic vibrations induced by wind or earthquake loads. The soft storey will be made up of concrete and its columns, beams, and slab sizes will be smaller than columns, beams, and slab sizes other stories of the building[1]. The height, member sizes of soft storey will be devised based on the principle of TMD i.e. the natural frequency of TMD (soft storey) should have same natural frequency as that of main building.

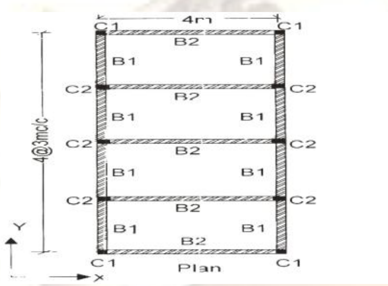
Bakre, S.V. (2002), weak soft storey at building top decreases the seismic response of building. Thawre, R.Y(2004). Increase in percentage of mass ratio of TMD increases the effectiveness of TMD. Pinkaew T., Lukkunaprasit P. And Chatupote P. (2003) investigated the effectiveness of TMD under ground motion. Although TMD cannot reduce the peak displacement of the controlled structure after yielding, it could significantly reduce damage of the structure. Sadek, F (1997), found that for a TMD to be optimum, its natural frequency should be very close to the natural frequency of the structure and its damping ratio should be more that of the structure.

1.1Tuned Mass Damper

Sadek, F (1997), proposed optimum parameters of TMD. These optimum parameters include optimum frequency ratio and mass ratio. TMD with optimum frequency ratio given by Sadek, F (1997), is considered. This TMD being made up of concrete has same damping ratio as that of the main building. TMD is considered to have rectangular columns with nearly same B/D ratio.

2. Analysis of buildings with TMD

In this building with TMD of same damping as that of the main building are analyzed using direct integration approach. Response of rectangular plan shape building is obtained under three past-recorded earthquakes. The building details and geometrical properties of the structures analyzed are shown in Fig. 1. Height of all the floors including ground floor is taken as 3m, with plinth level at 1.5m heights from footing level. Young's modulus of elasticity for concrete is taken as 23560 Mpa and mass density is 2.4t/m^3. First model (Model 1) is the building without TMD and second model (Model 2) is the building with TMD. Schematic representation of building without and with TMD is shown in Fig. 2 and 3.



C1-230X230
C2-230X400
B1-230X400
B2-230X400
Slab 100mm thick

Figure 1. Plan of building

In order to tune the natural frequency of TMD with that of building, it is required to know natural frequencies and natural mode shapes of building and TMD. Natural frequencies of building are also needed to calculate the proportional damping coefficients C_1 and C_2 for direct integration method. Through SAP, results for the first five modes of building are presented. It is seen that for all buildings more than 95% mass gets excited in the first five mod

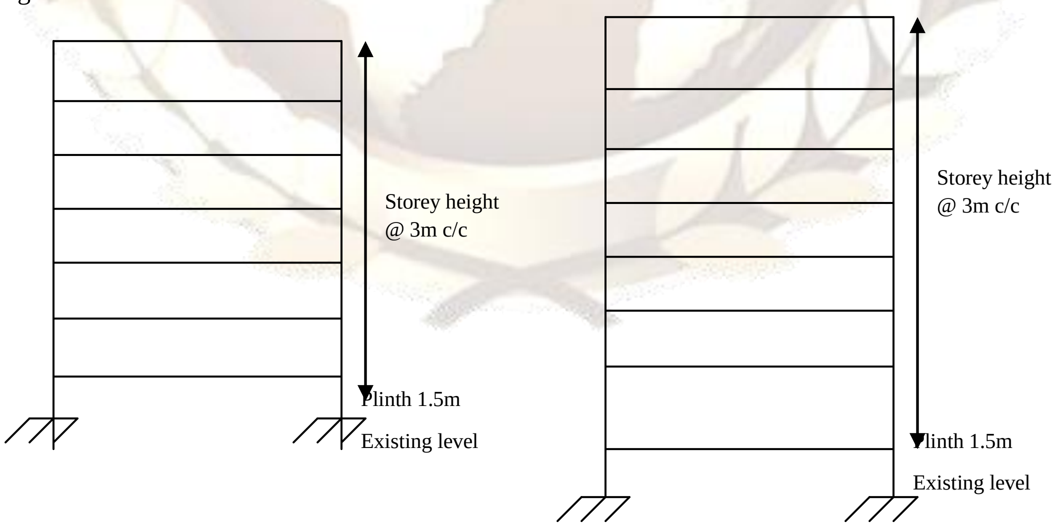


Figure 2. (a) Elevation of building without TMD **(b)** Elevation of building with TMD

Table 1. Free vibration characteristics of building (modal 1)

Total mass=525t		
Mode 1	Frequency	
	rad/sec	cyc/sec
1	6.3	1
2	6.83	1.1
3	7.66	1.22
4	19.63	3.125
5	20.94	3.33

2.1TMD Parameters

Sadek, F (1997), proposed criteria for optimum TMD parameters. He formulated optimum frequency ratio and optimum damping ratio for Multi Degree of Freedom System. He proposed that effective mass ratio should be used for calculating optimum parameters of TMD. Effective mass ratio is the ratio of mass of TMD to normalized modal mass of building. As per Sadek, F (1997), effective mass ratio (μ) and optimum frequency ratio (fopt), is given by following Equation.

$$\mu = \frac{m}{M_1}$$

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

Where, m = mass of TMD; M_1 = modal mass of building; $f_{opt}=\omega_{d□}□/\omega$; ω_d = First natural frequency of TMD;□ω□ = First natural frequency of building; β = Damping ratio of main building.

Once optimum parameters are known, sizes of columns, beams and slab thickness of TMDs are arrived at. Details of these TMDs are given in Table 4.

Table 2. Basic building characteristics to find optimum TMD parameters.

System	Fundamental frequency(Hz)	Modal Mass(t)	Amplitude of Ist Mode
Rectangular building	1.0	525	1.0

Table 3. Optimum parameters of TMD

Mass Ratio (□ □)	Tuning Ratio (f_{opt})	Mass of TMD M_1 (t)	1st Natural Frequency of TMD□$_d$(Hz)
0.02	0.98	10.1	1.284
0.03	0.97	15.15	1.271

Table 4. Details of TMD

Mass Ratio (%)	Colum size		Beam size		Slab thickness(mm)	Total mass(t)	Actual mass(%)
	C_1	C_2	B_1	B_2			
2	76x76	76x130	76x130	76x185	70	10.4	1.98
3	84x84	84x130	84x230	84x280	105	15.67	2.98

3. Free Vibration Analysis

After arriving at TMD, its free vibration analysis is carried out. Natural frequencies and natural mode shapes of TMD are extracted from the analysis. It can be seen that mass and first natural frequency of all TMDs nearly matches with the one obtained from Sadek, F(1997) parameters that are presented in Table 3. From the results of free vibration analysis, it is seen that frequency of Modal 2 in almost all cases is less than frequency of corresponding Modal 1.

Table 5. Free vibration characteristics of TMDs

Mode No	Frequency			
	2%		3%	
	rad/sec	cyc/sec	rad/sec	cyc/sec
1	6.38	1.0165	6.21	0.99
2	6.5	1.035	6.4	1.02
3	7.27	1.157	7.4	1.177
4	9.43	1.5	10.13	1.613
5	12	1.9	11.5	1.83

Table 6. Free vibration characteristics of building with TMD

Mode No	Frequency			
	2%		3%	
	rad/sec	cyc/sec	rad/sec	cyc/sec
1	7.02	1.117	6.8	1.08
2	7.02	1.117	6.8	1.08
3	7.59	1.208	7.4	1.176
4	9.85	1.567	10.25	1.631
5	9.85	1.567	10.25	1.631

4. Response Analysis and Results

Analysis of Model 1 and Model 2 is carried out using Direct Integration Method. Three recorded time histories of the past earthquake are used for the analysis. Each time history is applied in both directions. For each time history, maximum displacement at the top of both models is noted in both directions. Model 2 is considered to be building with 2%TMD and 3%TMD. For comparative study, response of Mode1 1 and Mode1 2 with TMDs of two different mass ratios is presented together in table 8. These response quantities are noted for outer and inner columns. Bending moments and axial forces are noted in both the directions. C_1 is stiffness proportionality coefficient and C_2 is mass proportionality coefficient in table7.

Table7. Proportional Damping Coefficients

System	Combination of Frequencies	Proportional Damping Coefficients	
		C1=2□ □ □□□ □□	C1=2□ □ □ □ □ □
Building without TMD	1st & 3rd	0.00577	0.216
Building with 2% TMD	1st & 5th	0.00593	0.204
Building with 3% TMD	1st & 5th	0.00586	0.2044

Table 8. Displacements of building under different earthquake excitation applied in X-direction

Time History	Maximum Displacement at the top of the building				
	Building without TMD	Building with TMD		Percentage Reduction	
		2%TMD	3%TMD	2%TMD	3%TMD
E L Centro	1.56	0.9325	0.9378	40.2	39.9
Taft	0.5146	0.4372	0.423	15	178
Dharamshala	0.2463	0.2358	0.2124	4.3	13.7

Table 9. Displacements of building under different earthquake excitation applied in Y-direction

Time History	Maximum Displacement at the top of the building				
	Building without TMD	Building with TMD		Percentage Reduction	
		2%TMD	3%TMD	2%TMD	3%TMD
E L Centro	1.1865	1.23	1.08	-3.66	9
Taft	0.693	0.6607	0.593	5.7	15.2
Dharamshala	0.3	0.2182	0.2104	27.2	29.8

Table 10. Response under different earthquake excitation applied in x-direction

Quantity	Level	Colum	Modal	EL-Centro	Taft	Dharamshala
Axial Force(KN)	Footing Level	C1	M1	3543	1169	570
			M2	2200	982	383
		C2	M1	2966.5	1010	518
			M2	1837.5	873	356
	1st Floor Level	C1	M1	5030.5	1652	802
			M2	3423.5	1887	736
		C2	M1	4250	1440	727.5
			M2	2963	1677	673
Bending Moment(KN-m)	Footing Level	C1	M1	542	176	90
			M2	269	155.5	55.5
		C2	M1	838	293	139
			M2	409	217	99
	1st Floor Level	C1	M1	846	288	135.5
			M2	925	611	185
		C2	M1	1250.5	432.5	190
			M2	1030.5	577.5	217

Table 11. Response under different earthquake excitation applied in y-direction

Quantity	Level	Column	Modal	EL-Centro	Taft	Dharamshala
Axial Force(KN)	Footing Level	C1	M1	3851	2362	1362
			M2	2732	1391.5	479
		C2	M1	1149	165.2	801.5
			M2	197	107.5	45
	1st Floor Level	C1	M1	3024.5	2085.5	1216
			M2	2212	1160	428
		C2	M1	1030	143.9	727.5
			M2	205	110	49
Bending Moment(KN-m)	Footing Level	C1	M1	424	211	91.5
			M2	409	181	82
		C2	M1	1677	835	361.5
			M2	783	331	148
	1st Floor Level	C1	M1	571	308	119.5
			M2	623	286.5	115
		C2	M1	1974	969.5	416
			M2	1162	534	212

(a) (b)

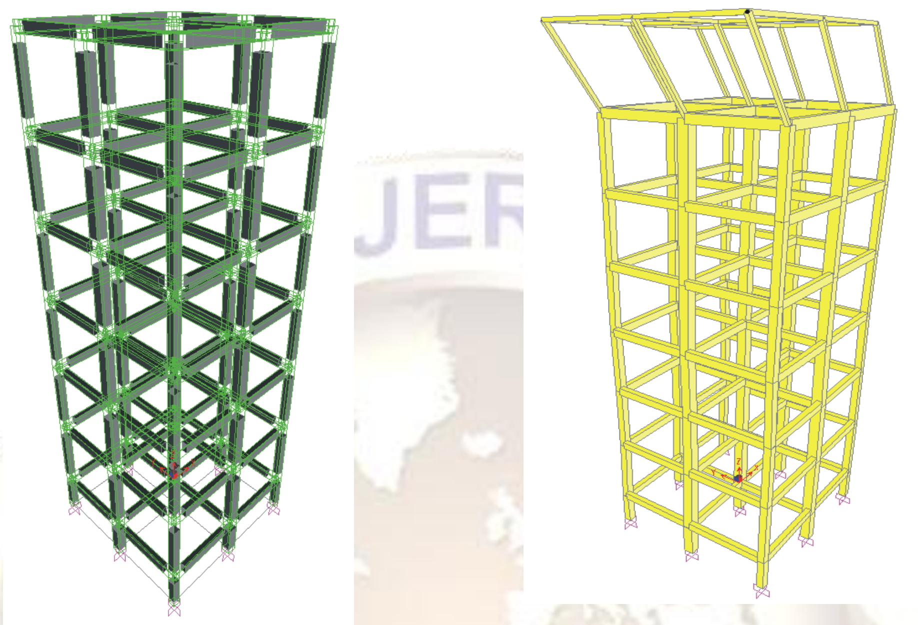


Figure 3. (a) Building without TMD (b) Building indicating soft storey at top

5.Conclusion

After analyzing a six storied building with rectangular shape by using FE software SAP 2000. Responses in the form of displacement, axial force & bending moment are noted. Following natural conclusion on the basis of received results can be formed.

- Simple TMD with optimum frequency ratio, provided in the form of soft storey at building top is found to be effective in reducing seismic response of building.
- In general, a soft storey at the top of building reduces top building deflection by about 10 to 50%
- Tuned mass damper in the form of soft storey of RCC is found to be effective in reducing seismic forces at critical locations like footing level and first floor level.
- Among 2% & 3% TMDs, 3% TMD is found better than 2% and 3% TMDs in reducing axial force, bending moment and displacement.
- Soft storey's presence also reduces the designing forces in the columns at all the floor levels.

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