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Use of Multiple Tuned Mass Dampers for Controlling Vibration in Frame Structure

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***Abstract*: Requirement of high-rise structure in construction industry is growing all over the world. These structures are construct light and flexible. Which have low damping value, makes them unsafe to undesirable vibration. This vibration due to wind and earthquake excitation creates problem to serviceability requirement of the structure and reduce structural integrity with possibilities of failure. Present time several techniques are used to reduce structural vibration induced due to wind and earthquake forces. With the increases demands for the safety, serviceability, durability, and reliability of structures. In this present study, for controlling vibration of frame structure Tuned mass dampers (TMD) are use. Tuned mass dampers known as to control the seismic response of high-rise buildings when subjected to earthquake generated ground motion. It is certainly going to regulate the natural frequencies and mode shapes. The efficiency of dampers is totally depend upon mass ratio and location of dampers. More particularly multiple tuned mass dampers are yet to be explore. Both single and multiple tuned mass dampers are analyzed with different aspect ratio of structure and various mass ratio of tuned mass dampers. Twenty-four structure have been modelled using ETABS. Response spectrum analysis has been carried out for different models in ETABS software. storey displacement, storey acceleration and model period Parameters used for study response of the structure when earthquake forces are applied.**

***Keywords*: tuned mass dampers, structural vibration, etabs, mass ratio, aspect ratio, response spectrum analysis.**

1. Introduction

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The oscillation may be periodic or non-periodic. Controlling vibration is important for machinery, space shuttle and airplane. Various techniques used to minimize vibration and increase stability.

A. Methods of Vibration Control

A several techniques have been using to produce better vibration control. These vibration control methods divided into four broad categories: passive control, active control, semi active control and hybrid control. Each of these will be discuss in following section.

1) Passive Control

A passive control system is one that does not require an external power source. All forces imposed by passive control devices develop as direct responses to the motion of the structure. Hence, sum of the energy of both the device and the primary system will be constant. Tuned mass damper, tuned liquid damper, base isolation are example of passive system.

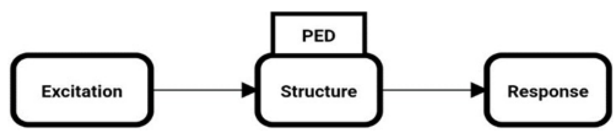

Fig. 1. Vibration reduction of structure by Passive Control

2) Active Control

Active control system has been as any control system in which an external power source is required to provide additional forces to the structure in a prescribed manner, by the use of actuators. The signals are sent to control the actuators and determine the feedback from the sensors provided on or through the structure. Due to the presence of an external power source, the force applied may either add or dissipate energy from the structure.

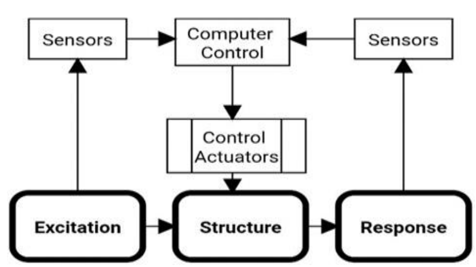

Fig. 2. Vibration reduction of structure by Active Control

3) Semi-Active Control

Semi active control systems act on the same principle of active control system but they differ in that their external energy

*Corresponding author: aagaikwad29@gmail.com requirement is smaller. These devices have an inherent stability in terms of bounded-input and output, as these do not add mechanical energy to the primary system. Therefore, it may be considered as controllable passive device. Semi-active control relies on the reactive forces that develop due to variable stiffness or damping devices rather than application of actuator forces.

As a result, semi-active control methods appear to combine the best features of fully active and fully passive systems, leaving them as the best in term acceptance for structural control.

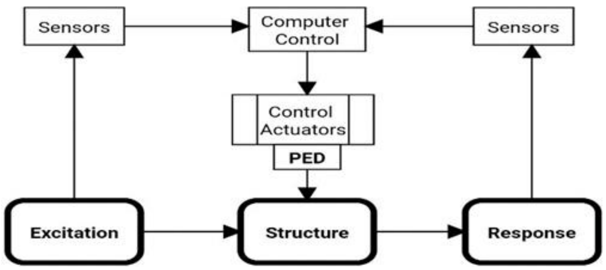

Fig. 3. Vibration reduction of structure by Semi-Active Control

4) Hybrid Control

Hybrid systems act on the combined use of passive and active control system. For example, a base isolated structure, which is equipped with actuator, which actively controls the enhancement of its performance.

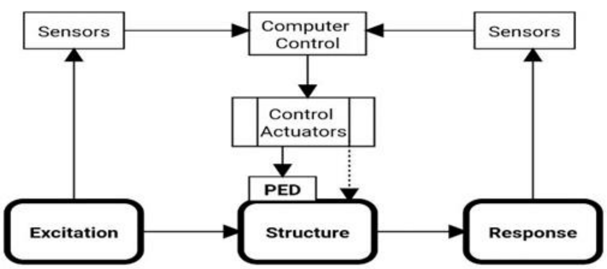

Fig. 4. Vibration reduction of structure by Hybrid Control

B. Tuned Mass Dampers

A Tuned mass damper (TMD) is a passive damping device, which utilizes a secondary mass attached to a main structure normally through spring and dashpot to reduce the dynamic response of the structure. It is widely used for vibration control in mechanical engineering systems. TMD popularly used to reduce vibrations of tall buildings and other civil engineering structures also. The secondary mass system is design to have the natural frequency, which is depended on its mass and stiffness, tuned to that of the primary structure. Mass for TMD varies from 1-10% of the structural mass.

2. Objective and Methodology

A. Objective

Objective of present work is to study the effect of single and multiple TMD on the dynamic response of multi-storey frame structures by the Response Spectrum Analysis with different parameters.

- To determine optimum reduction in vibration of structure by using tuned mass dampers with different aspect ratio of structure and mass ratio of TMD.
- To find out the change in the value of various structural parameters like storey displacement, storey acceleration and Modal period using response spectrum analysis.
- Response spectrum analysis of multi-storey frame with and without TMD.

B. Methodology

One of the basic needs in a structure design is to predict reliability the desired structure under specified loading condition. In designing structure equipped with tuned mass dampers, the most important design parameter is the property of dampers. Loading platform with hinge support use as tuned mass attached through dampers. First, the analysis of structure is carried out without dampers. Then the analysis of structure with single TMD and multiple TMD with different mass ratio of dampers. Trial and error method has been carry out to find the optimum mass ratio for the dampers in the building.

1) General Detail of Structure

The present work involves the study of structure with and without tuned mass dampers. The various aspect ratio and G+50 storey will be consider for the study.

2) Material property of building

- Grade of concrete M30 and grade of steel fe500 are use.

3) Dimension of structural member

- Size of Beam- Base to 50 storey 230mm X 600mm
- Size of column- Base to 25 storey 350mmX350mm
- Size of column -26 to 50 storey 350mmX300mm

4) Primary Load Case

- Dead load as per ETABS
- Live Load-3 KN/m^2
- Floor Finish- 1KN/m^2

5) Seismic Properties

- Seismic Load as per IS 1983:2016 (Table 1)

Table 1
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Particulars	Unit	Model-A	Model-B	Model-C	Model-D
Aspect ratio	-	1	1.4	1.6	2
Max. length in X-direction	m	25	30	40	50
Max. length in Y-direction	m	25	25	25	25
No. of floor	nos	G+50	G+50	G+50	G+50
Floor to floor height	nos	3	3	3	3
Total height of structure	m	153	153	153	153
Seismic zone	-	IV	IV	IV	IV
Response reduction factor	-	5	5	5	5
Importance factor	-	1	1	1	1
Soil condition	-	Medium	Medium	Medium	Medium

6) Tuned Mass Dampers to be used

Tuned mass damper attached to model structure by loading platform with hinge support and link. Single TMD provide at center of 50 storey and Multiple TMDs provided at center of 30, 35,40,45,50 stories.

Mass ratio of TMD with respect to self-weight of main structure is,

1. Single tuned mass Dampers Mass Ratio with respect to self-weight of structure 0.5%, 1%, 2.5% equipped in Model A1, B1, C1, and D1.
2. Multiple tuned mass Dampers Mass Ratio with respect to self-weight of structure 0.5%, 1%, 2.5% equipped in Model A2, B2, C2, and D2.

3. Results

All Etabs model has been Analysis by Response Spectrum Function. The significant parameters monitored so far were storey displacement, Storey Acceleration and model period for without damper model, single tuned mass dampers and multiple tuned mass with different location and different aspect ratio of building.

A. Storey Displacement

Without TMD, with single TMD and multiple TMD model are created in ETABS and for the same model analysis has been done for earthquake forces in X-direction and earthquake force in Y-direction. In addition, the result I mention result was compare to understand the behaviour of structure after installation of tuned mass dampers with conventional building.

Table 2
Summary of Storey Displacement for Model A, A1 & A2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Displacement in mm	Percentage Reduction in Displacement
X-direction			
Model A		432.555	-
Model A1	MR 0.5%	24.306	94.38%
	MR 1%	45.614	89.45%
	MR 2.5%	75.138	82.63%
Model A2	MR 0.5%	19.294	95.54%
	MR 1%	14.068	96.75%
	MR 2.5%	8.842	97.96%
Y-direction			
Model A		453.007	-
Model A1	MR 0.5%	25.299	94.42%
	MR 1%	51.268	88.68%
	MR 2.5%	79.329	82.49%
Model A2	MR 0.5%	18.609	95.89%
	MR 1%	12.513	97.24%
	MR 2.5%	8.809	98.06%

Table 3
Summary of Storey Displacement for Model B, B1 and B2 whenearthquake force applied in X-direction and Y-direction

Model		Maximum Storey Displacement in mm	Percentage Reduction in Displacement
X-direction			
Model B		365.077	-
Model B1	MR 0.5%	21.645	94.07%
	MR 1%	66.826	81.70%
	MR 2.5%	70.919	80.57%
Model B2	MR 0.5%	19.525	94.65%
	MR 1%	14.336	96.07%
	MR 2.5%	11.171	96.94%
Y-direction			
Model B		498.798	-
Model B1	MR 0.5%	23.586	95.27%
	MR 1%	87.858	82.39%
	MR 2.5%	90.778	81.80%
Model B2	MR 0.5%	23.197	95.35%
	MR 1%	16.161	96.76%
	MR 2.5%	12.895	97.41%

Table 4
Summary of Storey Displacement for Model C, C1 and C2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Displacement in mm	Percentage Reduction in Displacement
X-direction			
Model C		346.500	-
Model C1	MR 0.5%	67.084	80.64%
	MR 1%	70.033	79.79%
	MR 2.5%	70.486	79.66%
Model C2	MR 0.5%	18.618	94.63%
	MR 1%	14.718	95.75%
	MR 2.5%	13.696	96.05%
Y-direction			
Model C		520.105	-
Model C1	MR 0.5%	95.917	81.56%
	MR 1%	34.966	93.28%
	MR 2.5%	152.541	70.67%
Model C2	MR 0.5%	26.433	94.92%
	MR 1%	19.940	96.17%
	MR 2.5%	17.267	96.68%

Table 5
Summary of Storey Displacement for Model D, D1 and D2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Displacement in mm	Percentage Reduction in Displacement
X-direction			
Model D		318.848	-
Model D1	MR 0.5%	60.476	81.03%
	MR 1%	45.945	85.59%
	MR 2.5%	21.369	93.30%
Model D2	MR 0.5%	14.974	95.30%
	MR 1%	16.427	94.85%
	MR 2.5%	14.638	95.41%
Y-direction			
Model D		561.916	-
Model D1	MR 0.5%	101.170	82.00%
	MR 1%	58.212	89.64%
	MR 2.5%	24.156	95.70%
Model D2	MR 0.5%	21.153	96.24%
	MR 1%	20.389	96.37%
	MR 2.5%	23.683	95.79%

B. Storey Acceleration

Similar model used to find out the maximum storey acceleration when earthquake force applied in X-direction and Y-direction. After analysis, I got result. The result is used to compared and understand behaviour of structure after installation of dampers. In addition, the percentage of reduction of storey acceleration due to installation of Single TMD and Multiple TMD.

Table 6
Summary of Storey Acceleration for Model A, A1 & A2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Acceleration in mm/sec^2	Percentage Reduction in Acceleration
X-Direction			
Model A		176.270	-
Model A1	MR 0.5%	105.230	40.30%
	MR 1%	94.140	46.59%
	MR 2.5%	92.960	47.26%
Model A2	MR 0.5%	86.660	50.84%
	MR 1%	93.458	46.98%
	MR 2.5%	117.620	33.27%
Y-Direction			
Model A		179.090	-
Model A1	MR 0.5%	101.630	43.25%
	MR 1%	90.701	49.35%
	MR 2.5%	91.680	48.81%
Model A2	MR 0.5%	78.390	56.23%
	MR 1%	88.341	50.67%
	MR 2.5%	109.570	38.82%

Table 7
Summary of Storey Acceleration for Model B, B1 and B2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Acceleration in mm/sec^2	Percentage Reduction in Acceleration
X-Direction			
Model B		165.640	
Model B1	MR 0.5%	96.120	41.97%
	MR 1%	85.230	48.55%
	MR 2.5%	90.430	45.41%
Model B2	MR 0.5%	85.270	48.52%
	MR 1%	87.888	46.94%
	MR 2.5%	105.984	36.02%
Y-Direction			
Model B		189.160	
Model B1	MR 0.5%	91.100	51.84%
	MR 1%	95.880	49.31%
	MR 2.5%	99.060	47.63%
Model B2	MR 0.5%	100.078	47.09%
	MR 1%	100.232	47.01%
	MR 2.5%	105.702	44.12%

Table 8
Summary of Storey Acceleration for Model C, C1 and C2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Acceleration in mm/sec^2	Percentage Reduction in Acceleration
X-Direction			
Model C		161.940	-
Model C1	MR 0.5%	86.640	46.50%
	MR 1%	80.680	50.18%
	MR 2.5%	92.090	43.13%
Model C2	MR 0.5%	83.880	48.20%
	MR 1%	82.319	49.17%
	MR 2.5%	97.140	40.01%
Y-Direction			
Model C		193.890	
Model C1	MR 0.5%	102.570	47.10%
	MR 1%	95.010	51.00%
	MR 2.5%	108.999	43.78%
Model C2	MR 0.5%	101.350	47.73%
	MR 1%	95.570	50.71%
	MR 2.5%	106.590	45.03%

Table 9
Summary of Storey Acceleration for Model D, D1 and D2 when earthquake force applied in X-direction and Y-direction

Model		Maximum Storey Acceleration in mm/sec^2	Percentage Reduction in Acceleration
X-Direction			
Model D		155.080	-
Model D1	MR 0.5%	80.050	48.38%
	MR 1%	81.567	47.40%
	MR 2.5%	96.990	37.46%
Model D2	MR 0.5%	68.290	55.96%
	MR 1%	67.026	56.78%
	MR 2.5%	64.500	58.41%
Y-Direction			
Model D		203.010	-
Model D1	MR 0.5%	105.010	48.27%
	MR 1%	90.669	55.34%
	MR 2.5%	90.820	55.26%
Model D2	MR 0.5%	80.640	60.28%
	MR 1%	85.309	57.98%
	MR 2.5%	72.380	64.35%

C. *Model Period*

Similar model used to carry out model period when earthquake forces applied in X-direction and Y-direction. In addition, the result compare to understand the behavior after installation of single TMD and multiple TMD

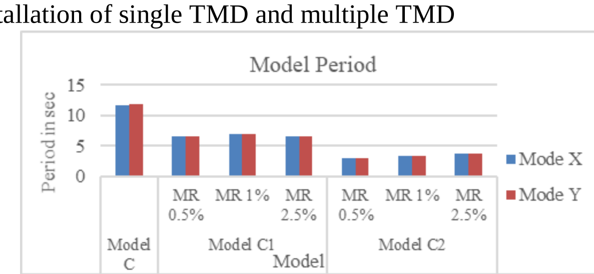

Fig. 5. Model period for Model A, A1 and A2 when earthquake force in X- direction and Y-direction

Table 10
Model period for Model C, C1 and C2 when earthquake force in X-direction and Y-direction.

	Model C	Model C1			Model C2		
		MR 0.5%	MR 1%	MR 2.5%	MR 0.5%	MR 1%	MR 2.5%
Unit	sec	sec	sec	sec	sec	sec	sec
Mode X	11.585	6.612	6.909	6.598	3	3.291	3.752
Mode Y	11.891	6.612	6.909	6.598	3	3.291	3.752

Table 11
Model period for Model B, B1 and B2 when earthquake force in X- direction and Y-direction

	Model B	Model B1			Model B2		
		MR 0.5%	MR 1%	MR 2.5%	MR 0.5%	MR 1%	MR 2.5%
Unit	sec	sec	sec	sec	sec	sec	sec
Mode X	11.499	3.851	6.556	6.414	3.636	3.525	3.102
Mode Y	11.502	3.782	4.983	6.414	3.636	2.966	2.132

Table 12
Model period for Model C, C1 and C2 when earthquake force in X- direction and Y-direction

	Mode C	Model C1			Model C2		
		MR 0.5%	MR 1%	MR 2.5%	MR 0.5%	MR 1%	MR 2.5%
Unit	sec	sec	sec	sec	sec	sec	sec
Mode X	11.585	6.612	6.909	6.598	3	3.291	3.752
Mode Y	11.891	6.612	6.909	6.598	3	3.291	3.752

Table 13
Model period for Model D, D1and D2 when earthquake force in X- direction and Y-direction

	Model D	Model D1			Model D2		
		MR 0.5%	MR 1%	MR 2.5%	MR 0.5%	MR 1%	MR 2.5%
Unit	sec	sec	sec	sec	sec	sec	sec
Mode X	11.721	6.694	5.181	3.906	3.808	3.891	4.217
Mode Y	12.821	7.694	6.181	4.906	4.208	4.021	4.317

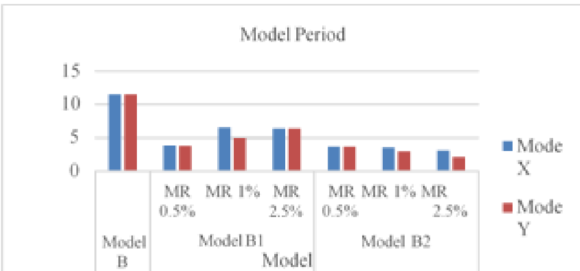

Fig. 6. Model period for Model B, B1 and B2 when earthquake force in X-direction and Y-direction

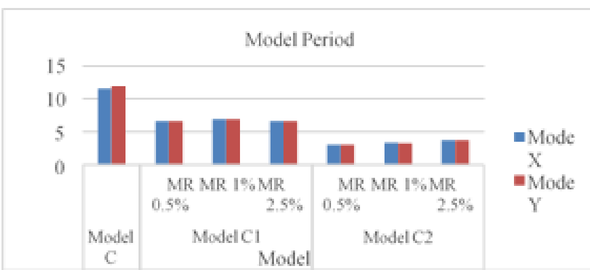

Fig. 7. Model period for Model C, C1 and C2 when earthquake force in X-direction and Y-direction

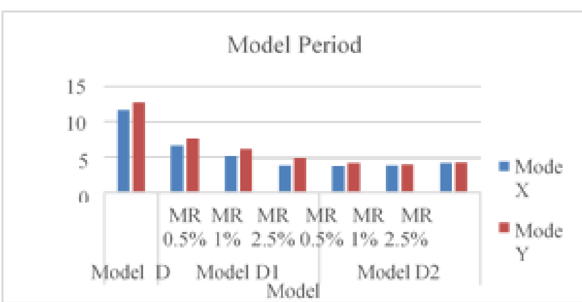

Fig. 8. Model period for Model D, D1 and D2 when earthquake force in X-direction and Y-direction

4. Conclusion

- Use loading platform with hinged support gives satisfying reduction in vibration when earthquake load applied in X-direction and Y-direction.
- From the study, TMD installed structure efficiently reduce storey displacement, storey acceleration, Storey force when earthquake forces applied on X and Y direction.
- It observed that, single tuned mass damper model A1 with MR 0.5% is efficiently reduced earthquake excitation.
- From the study concluded that multiple tuned mass damper, model D2 with MR 2.5 % efficiently reduce vibration of structure.
- From the study concluded that Square shape structure is effective for single tuned mass dampers with economical perspective and multiple tuned mass dampers are effective for square and rectangle shape structure.

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