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Effectiveness of Location and Number of Multiple Tuned Mass Damper for Seismic Structures

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Abstract: ***Tuned mass dampers (TMD) are one of the most reliable devices to control the vibration of the structure. The optimum mass ratio required for a single tuned mass damper (STMD) is evaluated corresponding to the fundamental natural frequency of the structure. The effect of STMD and Multiple tuned mass dampers (MTMD) on a G+20 storey structure are studied to demonstrate the damper's effectiveness in seismic application. The location and number of tuned mass dampers are studied to give best structural performance in maximum reduction of seismic response for El Centro earthquake data. The analysis results from SAP 2000 software tool shows damper weighing 2.5% of the total weight of the structure effectively reduce the response of the structure. Study shows that introduction of 4-MTMD at top storey can effectively reduce the response by 10% more in comparison to single tuned mass damper. The use of MTMD of same mass ratio that of STMD is more effective in seismic response.***

Keywords: TMD, STMD, MTMD, SAP 2000, El-Centro earthquake, response of the structure.

I. INTRODUCTION

During earthquake the structure ineffective in resisting the seismic load can cause catastrophic disaster for human life and for the nation. It is important that the structure should withstand the external excitation. This can be achieved by increasing flexibility of the structure.

The increase in flexibility causes discomfort for occupants inside the structure during earthquake. So the response reduction of the structure plays a key role in structural engineering during earthquake Generally earthquake resistant structures are equipped with lateral load resisting mechanism to reduce seismic response, one such mechanism is Tuned mass dampers (TMD) which be able to effectively decrease the structural response during earthquake. A TMD is a passive damping system as shown in fig 1 comprises of a secondary mass, a spring and a dashpot attached to the main structure which reduces the structural response during earthquake.TMD has widely been used in multistory structures , bridges, industries and other civil structures.

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The TMD designed for natural frequency of the structure will oscillate in the opposite direction of the main structural vibrations. Due to oscillation against the direction of the lateral force an inertia force will be acting on the structure due to which the TMD mitigates the response of the structure.

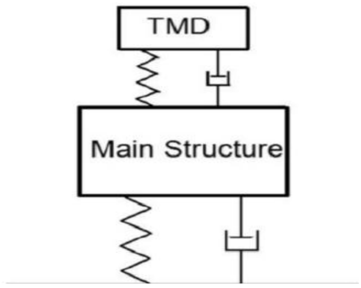

Fig-1 Schematic representation of tuned mass damper

II. OBJECTIVES OF STUDY

1. To perform primary analysis of a G+20 storey structure
2. Study the response of the STMD by placing at various locations of the building
3. Study the response of the MTMD by placing at various locations of the building.

III. METHODOLOGY

This paper emphasis the optimum location and number of dampers required to decrease the response of the structure. The TMD and multiple tuned mass dampers (MTMD) are designed for the fundamental natural frequency of the structure.

Table-I: The geometrical parameter of the structure

Type of building	special moment resisting structure (SMRF)
Number of storey	G+20 storey
Storey height of each storey	3.05m
Structural type	RCC framed structure
Grade of concrete	M30
Grade of steel	Fe500
Size of the columns	300X750mm 400X900 mm
Size of beams	300X600 mm 400X600 mm 500X600 mm 600X600 mm
Depth of the slab	150mm
Live load	$3kN/m^2$

Floor load	1kN/m^2
Wall load	6kN/m (AAC-Autoclaved aerated concrete blocks)
Importance factor	1.5
Reduction factor	5
Soil type	III (Soft soil)
Seismic zone factor	0.36 for zone V
Damping ratio	5%

Based on location and number of TMD, 17 models have been considered for study using SAP 2000 software

Numerous iteration has been carried out to get the optimum mass ratio of the TMD that decrease maximum response of the structure for El-Centro earthquake data.

Table-II: Description of the models

Model no	Description
1	RCC structure without TMD at 20th storey
2	RCC structure with 0.5 % TMD at 20th storey
3	RCC structure with 1.0 % mass ratio of TMD at 20th storey
4	RCC structure with 1.5 % mass ratio of TMD at 20th storey
5	RCC structure with 2.0 % mass ratio of TMD at 20th storey
6	RCC structure with 2.5 % mass ratio of TMD at 20th storey
7	RCC structure with 2.5 % mass ratio of TMD at 5th storey
8	RCC structure with 2.5 % mass ratio of TMD at 10th storey
9	RCC structure with 2.5 % mass ratio of TMD at 15th storey
10	RCC structure with 2- MTMD OF 2.5 % mass ratio at 20th and 19th storey
11	RCC structure with 2-MTMD OF 2.5 % mass ratio at 20th storey
12	RCC structure with 3-MTMD OF 2.5 % mass ratio at 20th ,19th and 18th storey
13	RCC structure with 3-MTMD OF 2.5 % mass ratio at 20th storey
14	RCC structure with 4-MTMD OF 2.5 % mass ratio at 20th ,19th ,18th and 17th storey
15	RCC structure with 4- MTMD OF 2.5 % mass ratio at 20th storey
16	RCC structure with 5- MTMD OF 2.5 % mass ratio at 20th ,19th ,18th ,17th and 16th storey
17	RCC structure with 5- MTMD OF 2.5 % mass ratio at 20th storey

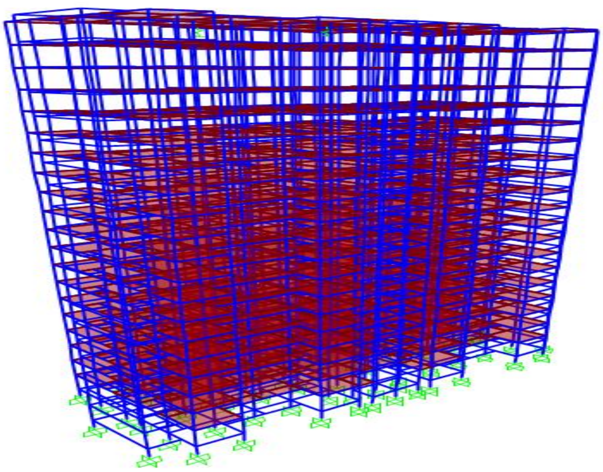

Fig-2 3D model of the structure

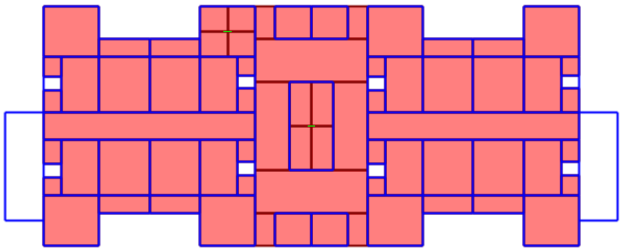

Fig-3 Plan view of 2-MTMD

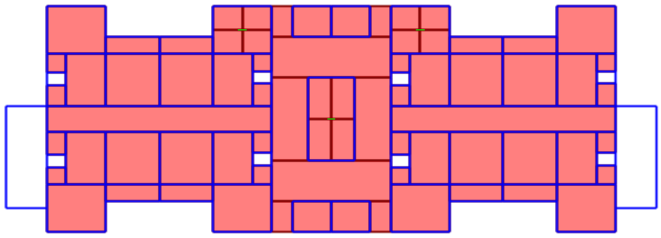

Fig-4 Plan view of 3-MTMD

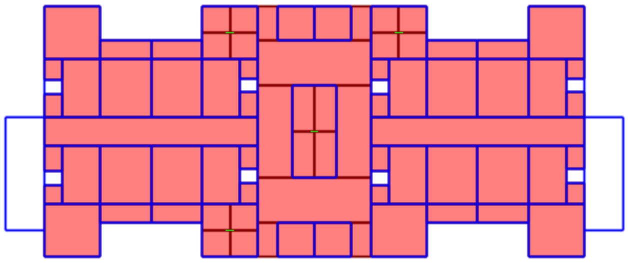

Fig-5 Plan view of 4-MTMD

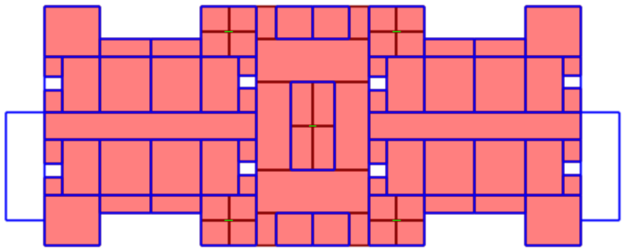

Fig-6 Plan view of 5-MTMD

IV. DETERMINATION OF OPTIMUM PARAMETER OF TMD

The following formulae are used to determine the optimum parameters of TMD

Frequency of damper $f_d = \frac{f_n}{1+\mu}$ (1)

Optimum damping ratio $\zeta opt = \sqrt{\frac{3\mu}{8(1+\mu)^3}}$ (2)

Natural frequency of TMD, $\omega_d = \sqrt{\frac{k_d}{m_d}}$ (3)

Damping ratio of TMD $\xi_d = \frac{c_d}{2m_d\omega_d}$ (4)

Frequency of MTMD damper

$\omega_j = \omega_T\ [1+\{j-(n+1)/2\}\beta/(n-1)]$ (5)

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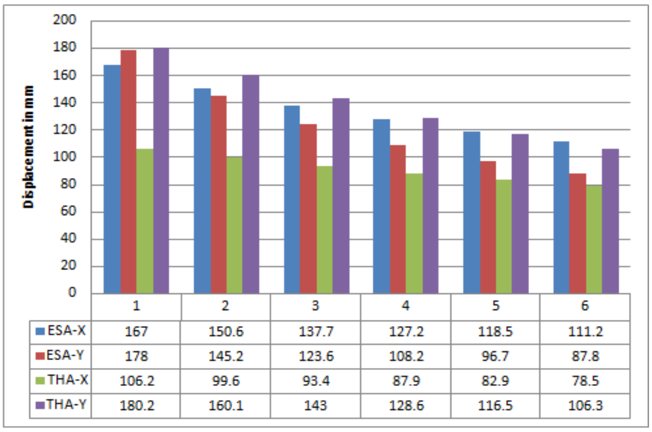
Where
f_n= natural frequency of the structure
k_d= stiffness of the damper
c_d= damping co-efficient
μ= mass ratio of damper
m_d= mass of the damper
ω_d= frequency of the damper
ω_j is the natural frequency of the jth damper, ω_T is the structural frequency and n is the number of TMD units
β is fractional bandwidth
n number of tuned mass dampers

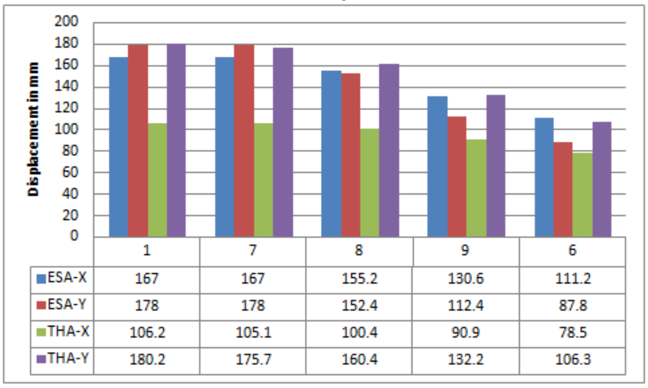
V. RESULTS AND OBSERVATION

To evaluate the performance of TMD, equivalent static analysis (ESA) and time history analysis (THA) and parameters such as displacement and time period are studied for various locations of the structure.



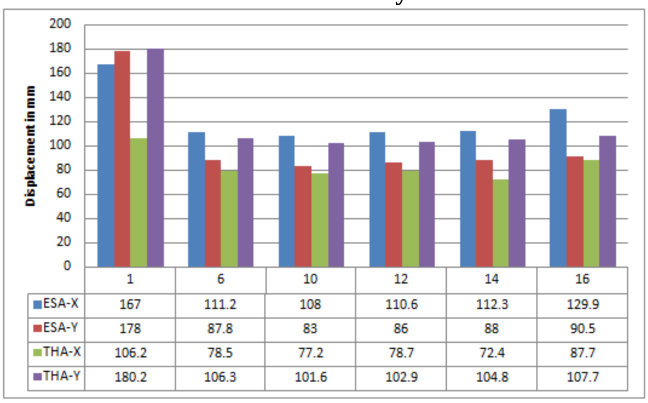
	1	2	3	4	5	6
ESA-X	167	150.6	137.7	127.2	118.5	111.2
ESA-Y	178	145.2	123.6	108.2	96.7	87.8
THA-X	106.2	99.6	93.4	87.9	82.9	78.5
THA-Y	180.2	160.1	143	128.6	116.5	106.3

Fig 7- Displacement of the structure for STMD at top storey



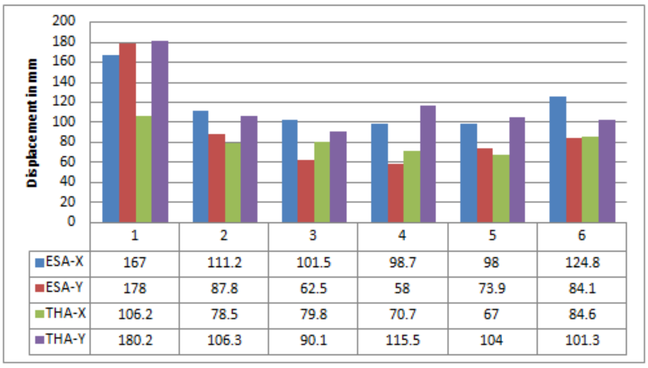
	1	7	8	9	6
ESA-X	167	167	155.2	130.6	111.2
ESA-Y	178	178	152.4	112.4	87.8
THA-X	106.2	105.1	100.4	90.9	78.5
THA-Y	180.2	175.7	160.4	132.2	106.3

Fig 8- Displacement of the structure for STMD at different storey



	1	6	10	12	14	16
ESA-X	167	111.2	108	110.6	112.3	129.9
ESA-Y	178	87.8	83	86	88	90.5
THA-X	106.2	78.5	77.2	78.7	72.4	87.7
THA-Y	180.2	106.3	101.6	102.9	104.8	107.7

Fig 9- Displacement of the structure for MTMD at different storey



	1	2	3	4	5	6
ESA-X	167	111.2	101.5	98.7	98	124.8
ESA-Y	178	87.8	62.5	58	73.9	84.1
THA-X	106.2	78.5	79.8	70.7	67	84.6
THA-Y	180.2	106.3	90.1	115.5	104	101.3

Fig 9- Displacement of the structure for MTMD at Top storey

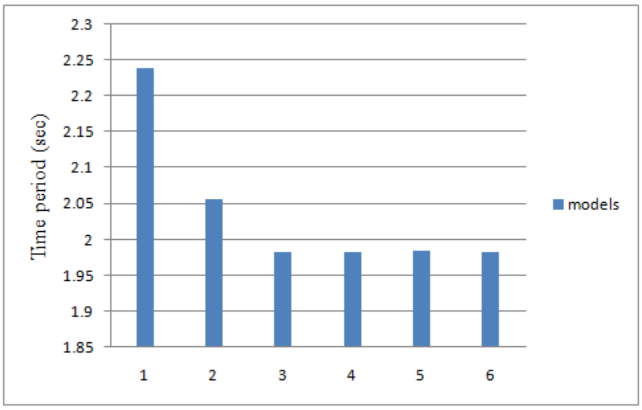


Fig-10 Variation of time period for STMD at top storey

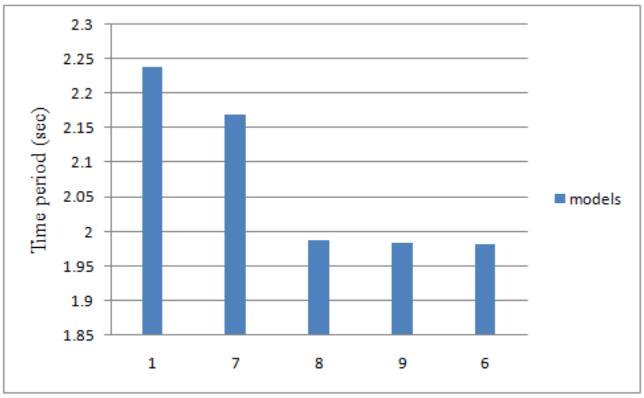


Fig-11 Variation of time period for STMD at different storey

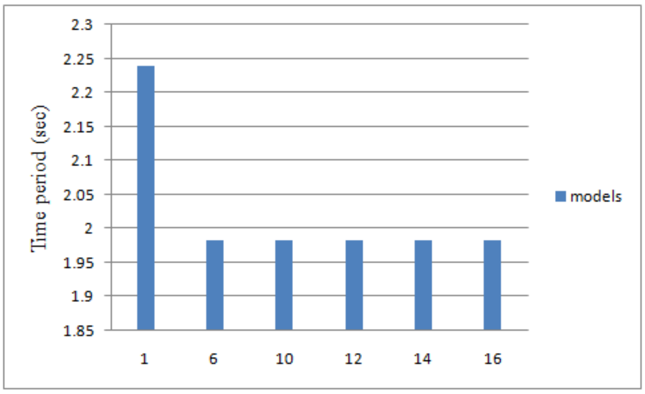


Fig-11 Variation of time period for MTMD at different storey

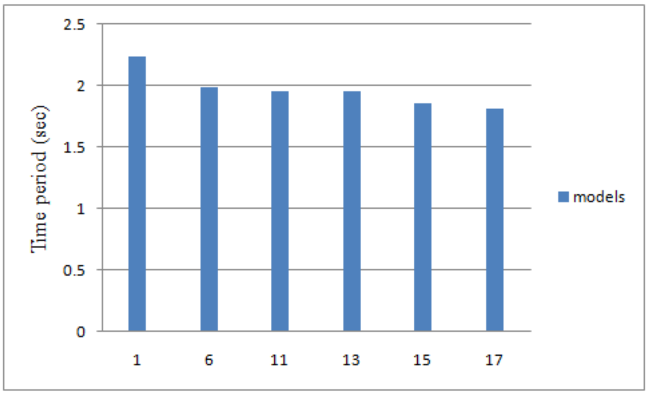


Fig-12 Variation of time period for MTMD at top storey

1. The maximum displacement is observed in model 1 i.e., bare frame model without TMD.
2. The maximum reduction in displacement for single tuned mass damper is observed in model 6 i.e., bare frame with 2.5 % mass ratio located at 20th storey. The percentage reduction of model 6 in comparison to model 2 i.e., bare frame with 0.5 % mass ratio located at 20th storey is as under

	Equivalent Static Analysis		Time History Analysis	
Model	X	Y	X	Y
6	33.41	50.67	26.08	41
2	9.82	18.42	18.42	6.21

3. The least reduction in displacement for single tuned mass damper is observed in model 7 i.e., bare frame with 2.5 % mass ratio located at 5th storey when compared to other models with single tuned mass damper. The percentage reduction is

	Equivalent Static Analysis		Time History Analysis	
Model	X	Y	X	Y
7	No change	No change	1.03	2.5

4. The maximum displacement reduction for multiple tuned mass damper placing at different storey level is observed in model 10 i.e., bare frame with 2MTMD of 2.5 % mass ratio located at 20th and 19th storey. The maximum percentage reduction when compared to model 6 i.e., bare frame with 2.5 % mass ratio located at 20th storey is as under

	Equivalent Static Analysis		Time History Analysis	
Model	X	Y	X	Y
10	35.32	53.27	27.3	43.61
6	33.41	50.67	26.08	41

5. The maximum displacement reduction for multiple tuned mass damper placing at 20th storey is observed in model 15 i.e., bare frame with 4MTMD of 2.5 % mass ratio located at 20th storey. The maximum percentage reduction when compared to model 6 i.e., bare frame with 2.5 % mass ratio located at 20th storey is as under

	Equivalent Static Analysis		Time History Analysis	
Model	X	Y	X	Y
15	41.31	58.43	36.91	42.28
6	33.41	50.67	26.08	41 %

6. The maximum time period is observed in model 1 in comparison with models with tuned mass dampers.

The reduction in time period is maximum in model 17 i.e., 18.76 % compared to model 6 11.40%.

VI. CONCLUSION

1. The effectiveness of TMD increases based on optimum location and number of MTMD used.
2. MTMD are more advantageous over a STMD in controlling displacement
3. The optimum number of tuned mass dampers required is 2MTMD when placed at different storey and 4MTMD when placed at top storey

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