International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:10, No:6, 2016

Vibration Control of Building Using Multiple Tuned Mass Dampers Considering Real Earthquake Time History

Rama Debbarma, Debanjan Das

***Abstract*—**The performance of multiple tuned mass dampers to mitigate the seismic vibration of structures considering real time history data is investigated in this paper. Three different real earthquake time history data like Kobe, Imperial Valley and Mammoth Lake are taken in the present study. The multiple tuned mass dampers (MTMD) are distributed at each storey. For comparative study, single tuned mass damper (STMD) is installed at top of the similar structure. This study is conducted for a fixed mass ratio (5%) and fixed damping ratio (5%) of structures. Numerical study is performed to evaluate the effectiveness of MTMDs and overall system performance. The displacement, acceleration, base shear and storey drift are obtained for both combined system (structure with MTMD and structure with STMD) for all earthquakes. The same responses are also obtained for structure without damper system. From obtained results, it is investigated that the MTMD configuration is more effective for controlling the seismic response of the primary system with compare to STMD configuration.

***Keywords*—**Earthquake, multiple tuned mass dampers, single tuned mass damper, time history.

I. Introduction

IN recent years, the construction of lightly damped, flexible tall building by using high strength materials in regions of seismic risk has created concern in the structural engineering community. In recognition of the serviceability issues, structural engineering researchers have created artificial passive vibration control devices. Tuned mass damper is the oldest passive vibration control device. In dynamic vibration control of structures, the tuned mass damper (TMD) has been installed as an effective passive control device to mitigate the structural vibration. A TMD is a passive vibration control device consisting of a mass, damping, and a spring; it is attached to a main building structure to reduce any undesirable vibrations induced by earthquake loads. The natural frequency of the TMD is tuned in resonance with the fundamental mode of the building structure, so that the huge amount of the structural vibrating energy is transferred to the TMD and dissipated by the damping as the building structure is subjected to earthquake loads. MTMDs are more successful passive vibration control system. In these systems, MTMDs are tuned to several modes of structure vibration. In this present study, the top storey displacement, acceleration, base shear and inter storey drift of the buildings are obtained using MTMD for different real earthquake time history data. The MTMDs are installed at each storey level to mitigate any undesirable vibration induced by earthquake load. The performance of MTMDs spatially distributed in a primary structure, is investigated considering wind loads [1], [2]. Most of the researchers have applied MTMD for single degree system [3], [4]. It has been demonstrated that MTMD with distributed natural frequencies are more effective than a single TMD. The effectiveness and robustness of MTMD under dynamic load were studied [5]-[7].The present paper deals the effectiveness and robustness of MTMD to controlling the vibration of structure under real earthquake loads. It is investigated that MTMDs significantly reduce drift, acieration and force response of all types of buildings subjected to sinusoidal loads [8]. The design of MTMDs in an irregular building is presented and found that MTMD are so much effective then STMD [9]. It is found that dynamic response reduces due to wind and earthquake excitation using a number of passive and active TMD in tall building [10]. It is found that the optimal parameters of TMD considerably reduce the response of the structures for various types of seismic loading [11]. A numerical study is taken to evaluate the effectiveness and robustness of MTMDs system and the performance of structures in this study.

Rama Debbarma and Debanjan Das are with the Department of Civil Engineering, National Institute of Technology Agartala-799046, India (e-mail: ramadebbarma@gmail.com, dasdebanjan.324@gmail.com).

II. Description of STMD and MTMD System

The aim of designing MTMD is to tune damper parameters to the fundamental mode of vibration. It means that the natural damper frequency (or a group of dampers) ω_d must be close to the natural frequency of fundamental vibration mode of structure $(\omega_d \simeq \omega_s)$. Moreover, the damping coefficient of the damper must be appropriately chosen [12] and c_j is obtained using equations developed by [13] for the SDOF damper.

The optimum parameters of such damper (or group of MTMD) can be obtained by equations developed [14]. The optimal frequency ratio is determined from:

$$\frac{\omega_d^2}{\omega_s^2} = \frac{2+\mu}{2(1+\mu)^2} \quad (1)$$

where,

$$\mu = \frac{\sum_{j=1}^{n} m_j}{m_s}, \omega_s^2 = \frac{k_s}{m_s}, \omega_d^2 = \frac{k_d}{m_d}, m_d = \sum_{j=1}^{n} m_j \quad (2)$$

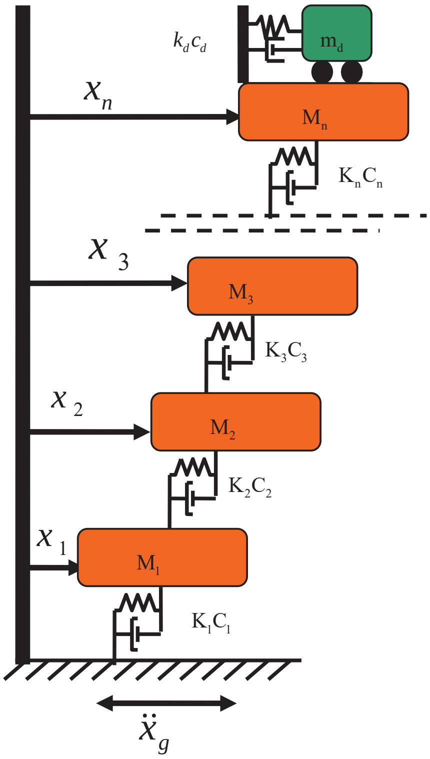

Fig. 1 Structure-STMD System

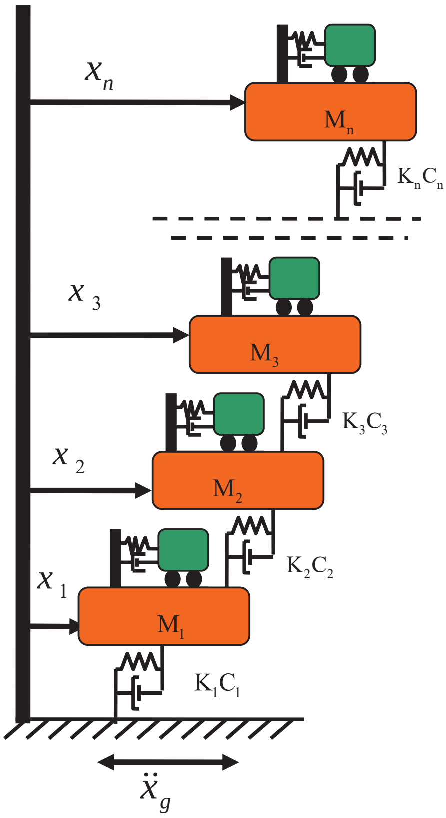

Fig. 2 Structure-MTMD System

III. The Equation of Motion of Structure and MTMD System

The equation of motion of a MDOF system attached with MTMD (as shown in Fig. 2) can be expressed as,

$$\tilde{M}\ddot{Y}+\tilde{C}\dot{Y}+\tilde{K}Y=-\tilde{M}\bar{r}\ddot{z}_b \tag{3}$$

where, $\mathbf{Y}=[x_s, x_1, x_2, ..., x_n]^T$ is the relative displacement vector, and $\bar{\mathbf{r}}=[0 \;\; \mathbf{I}]^T$ where I is an nx1 unit vector. $\tilde{M}, \tilde{C}$ and $\tilde{K}$ represent the mass, damping and stiffness matrix of the combined system:

$$\tilde{M}=\begin{bmatrix} M_s & 0 \\ 0 & m \end{bmatrix} \tag{4}$$

where, M_s is the mass matrix of the structure and is the matrix of dampers.

$$m=\mathrm{diag}\left[m_1, \;\; m_2, \;\; m_3, \;\; m_4, \;\; m_5 \;\; .... \;\; m_n\right]$$

The stiffness matrix $\tilde{K}$ of the considered system can be written in the block form below:

$$\tilde{K}=\begin{bmatrix} K_s+k_d & k^* \\ k^{*T} & k \end{bmatrix} \tag{5}$$

where, K_s is the stiffness matrix of structure.

$$k_d=\sum_{j=1}^{n} k_j, \; k^*=\left[-k_1 \;\; -k_2 \;\; -k_3 \;\; -k_4 \;\; -k_5 \;\; ... \;\; -k_n\right]$$

$$k=\mathrm{diag}\left[k_1, \;\; k_2, \;\; k_3, \;\; k_4, \;\; k_5, \;\; ... \;\; k_n\right]$$

The damping matrix of the system $\tilde{C}$ is in a form similar to that of the stiffness matrix $\tilde{K}$. The specific blocks of this matrix are shown:

$$\tilde{C}=\begin{bmatrix} C_s+c_d & c^* \\ c^{*T} & c \end{bmatrix} \tag{6}$$

where, C_S is the damping matrix of the structure and

$$c_d=\sum_{j=1}^{n} c_j, \; c^*=\left[-c_1 \;\; -c_2 \;\; -c_3 \;\; -c_4 \;\; -c_5 \;\; ... \;\; -c_n\right]$$

$$\frac{c_j}{2\sqrt{m_j k_j}}=\sqrt{\frac{3\mu_j}{8\left(1+\mu_j\right)}}, \; \xi j=\frac{c_j}{2m_j\omega_j}$$

$$c=\mathrm{diag}\left[c_1, \;\; c_2, \;\; c_3, \;\; c_4, \;\; c_5, \;\; ... \;\; c_n\right]$$

International Journal of Architectural, Civil and Construction Sciences
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IV. Numerical Study

A four storey building with MTMD subjected to real earthquake time history data is undertaken to study the performance of the proposed MTMD. The MTMD are distributed and installed at each storey. The building has the following mass and stiffness values:

$$m_1 = m_2 = m_3 = 102.94 \times 10^3 \text{ kg}, \quad m_4 = 95.45 \times 10^3 \text{ kg}$$

$$k_1 = k_2 = k_3 = 243.53 \times 10^6 \text{ N/m}, \; k_4 = 243.53 \times 10^6 \text{ N/m}$$

Unless mentioned otherwise, following nominal values are assumed for various parameters: damping ratio of structures, $\xi_s = 5\%$, mass ratio, $\mu = 5\%$. The fundamental natural frequency of the building is f_1 = 1.797264 hz, which is tuned by frequency of STMD and average frequency of MTMD system. The fundamental frequency of building and frequency of STMD and MTMD are obtained by using MATLAB program. The analysis is performed using software SAP 2000.

V. Results and Discussion

The variation of displacements of structures with time considering time history data of Kobe earthquake, Imperial Valley earthquake and Mammoth Lake earthquake using STMD, MTMD and with damper are shown in Figs. 3-5. It is observed that the MTMD is more effective to reduce the displacement of building. The maximum top storey displacement under Kobe earthquake is reduced 92.8% using MTMD and 31.15% using STMD. The 91.6% and 26.02% reduction of top displacement are observed using MTMD and STMD considering Imperial Valley earthquake. Similarly, it is also observed that 92.7% and 30.97% using MTMD and STMD under mammoth lake earthquake. The above displacement reductions are observed within the duration 10-15 s.

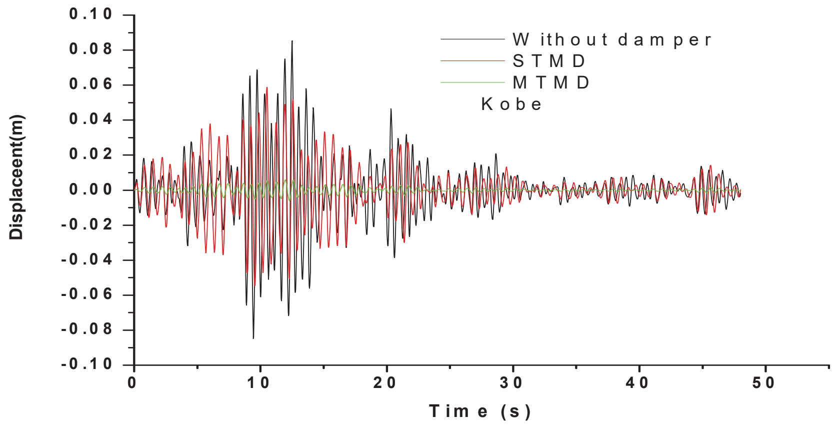

Fig. 3 Variation of displacement of structures with time considering time history data of Kobe earthquake

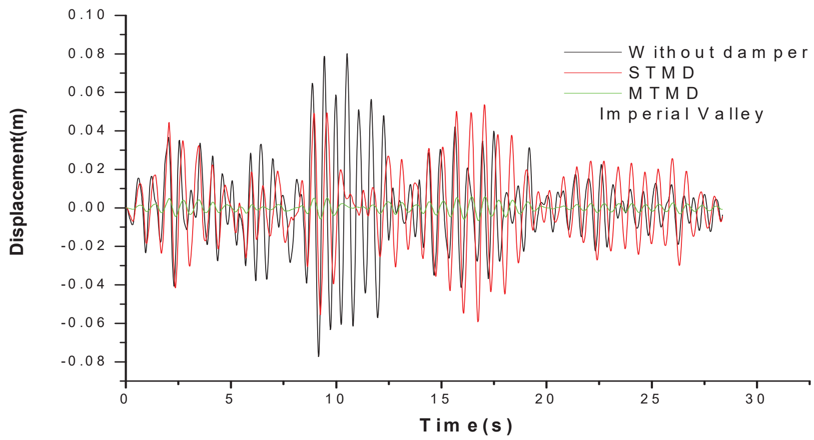

Fig. 4 Variation of displacement of structures with time considering time history data of Imperial Valley earthquake

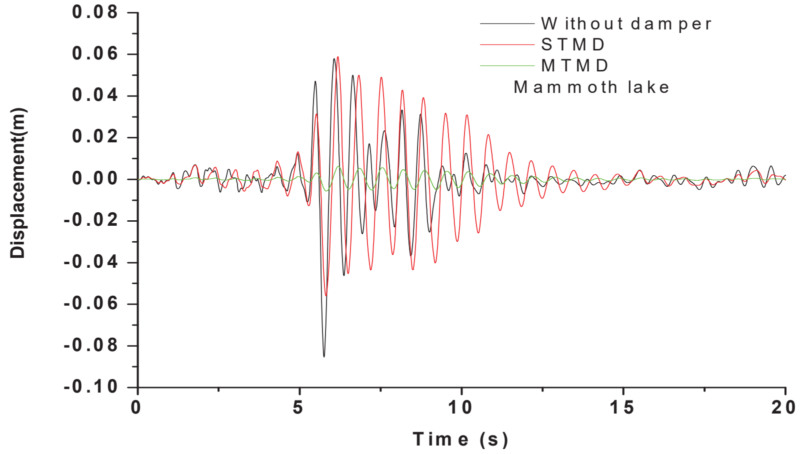

Fig. 5 Variation of displacement of structures with time considering time history data of Mammoth Lake earthquake

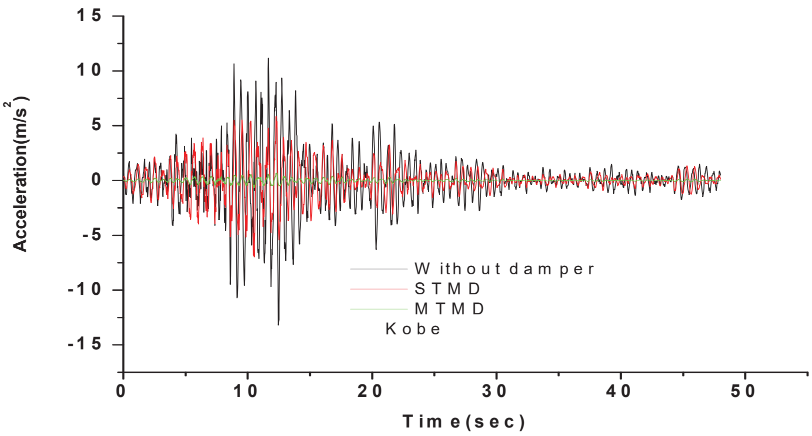

Fig. 6 Variation of accelerations of structures with time considering time history data of Kobe earthquake

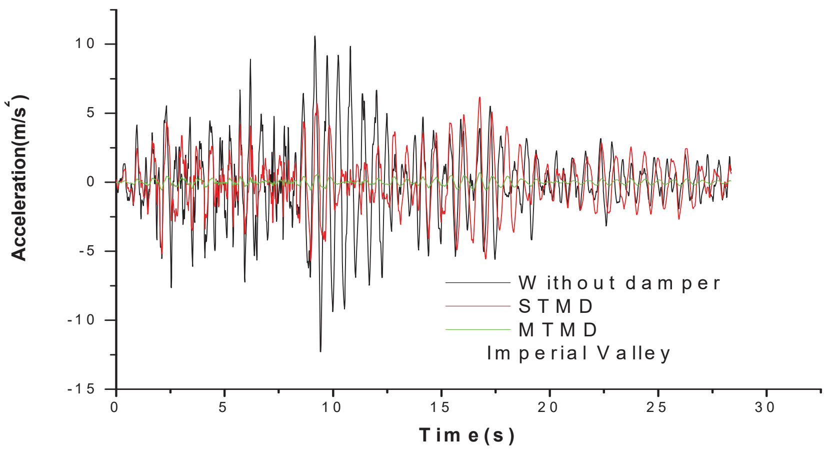

Fig. 7 Variation of accelerations of structures with time considering time history data of Imperial Valley earthquake

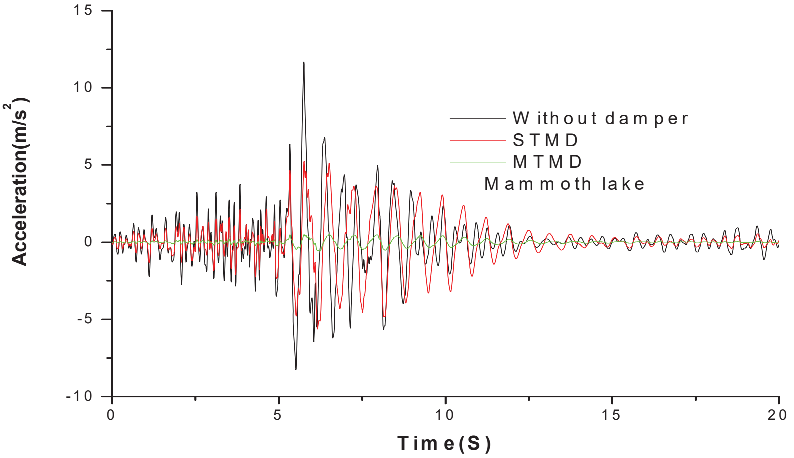

Fig. 8 Variation of accelerations of structures with time considering time history data of Mammoth Lake earthquake

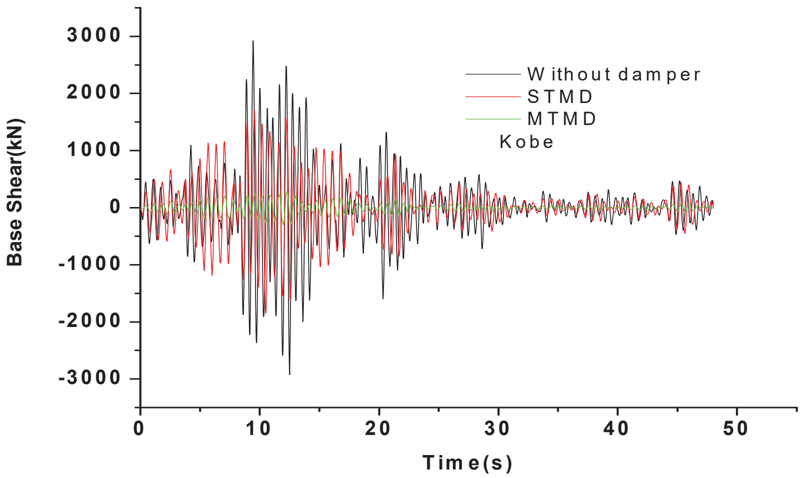

Fig. 9 Variation of base shear of structures with time considering time history data of Kobe earthquake

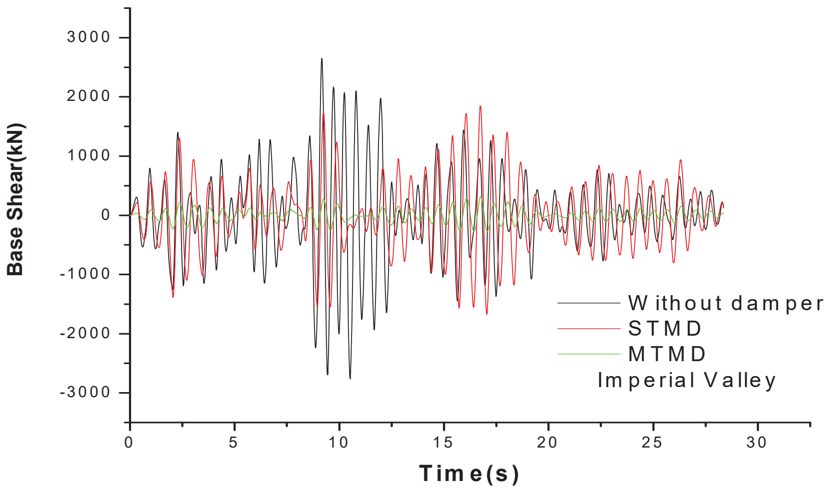

Fig. 10 Variation of base shear of structures with time considering time history data of Imperial Valley earthquake

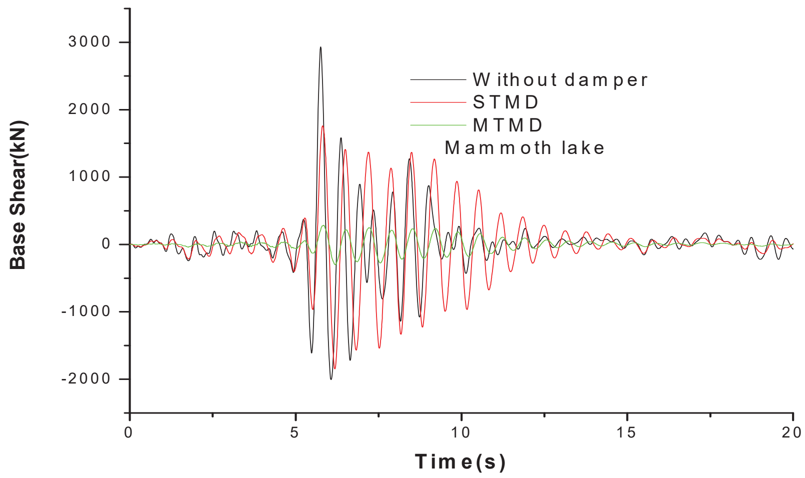

Fig. 11 Variation of base shear of structures with time considering time history data of Mammoth Lake earthquake

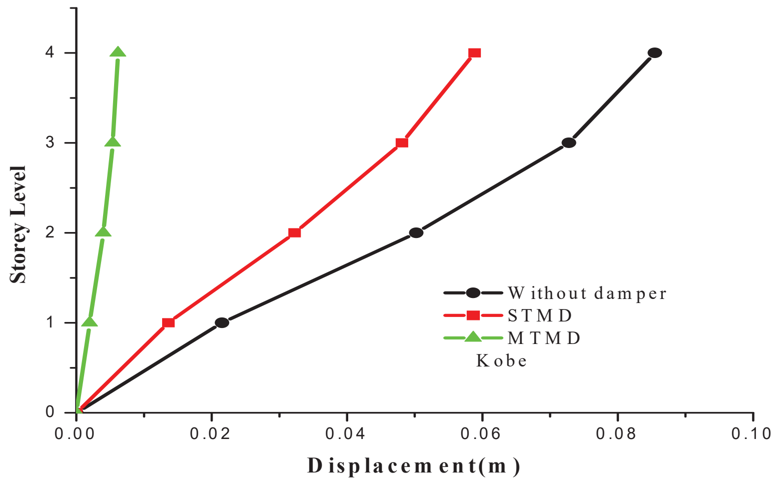

Fig. 12 Variation of displacement of structures considering time history data of Kobe earthquake

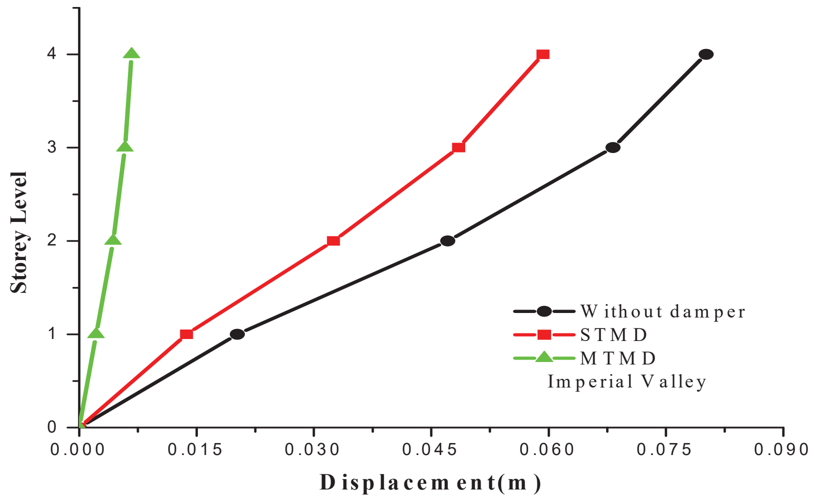

Fig. 13 Variation of displacement of structures considering time history data of Imperial Valley earthquake

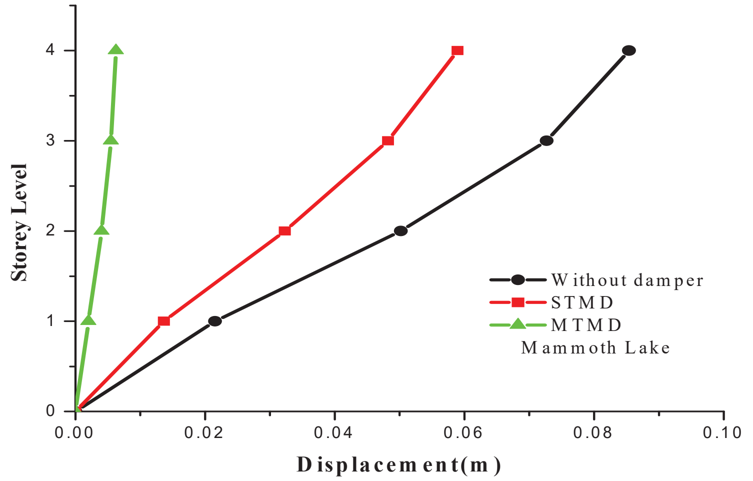

Fig. 14 Variation of displacement of structures considering time history data of Mammoth Lake earthquake

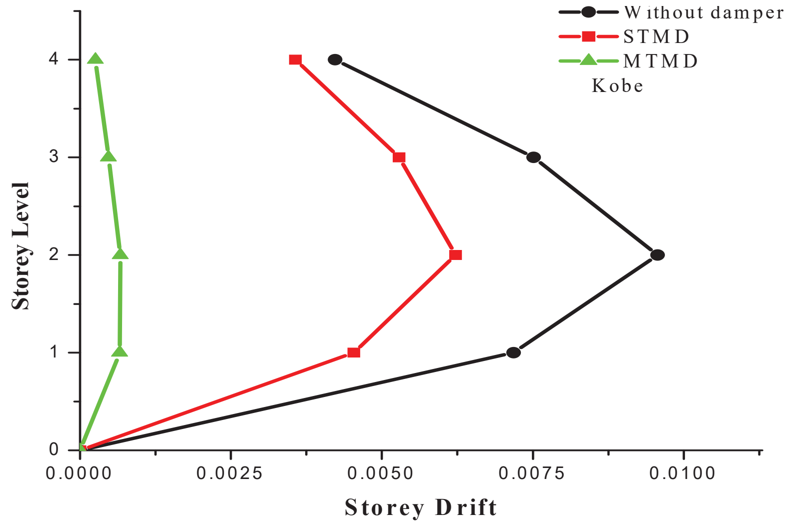

Fig. 15 Variation of storey drift of structures considering time history data of Kobe earthquake

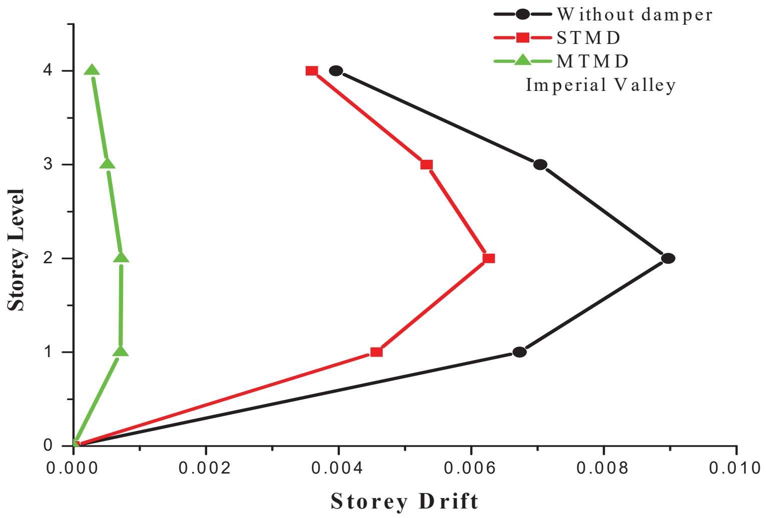

Fig. 16 Variation of storey drift of structures considering time history data of Imperial Valley earthquake

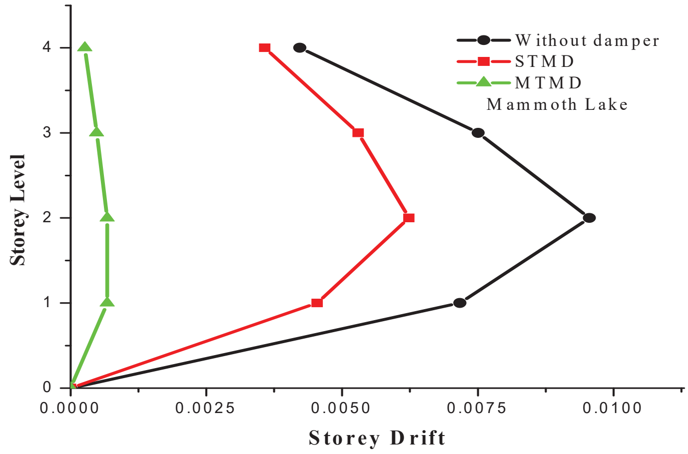

Fig. 17 Variation of storey drift of structures considering time history data of Mammoth Lake earthquake

TABLE I
DISPLACEMENTS OF BUILDING USING STMD, MTMD AND WITHOUT DAMPERS FOR DIFFERENT EARTHQUAKE

Displacements (m)				
Earthquakes	Level of floor	Without TMD	STMD	MTMD
Kobe	4	0.085483	0.058849	0.006166
	3	0.072801	0.048139	0.005395
	2	0.050253	0.032273	0.003976
	1	0.021544	0.013612	0.001975
Imperial Valley	4	0.080135	0.059277	0.006688
	3	0.068246	0.048489	0.005852
	2	0.047109	0.032508	0.004312
	1	0.020196	0.013711	0.002142
Mammoth Lake	4	0.085381	0.058931	0.006239
	3	0.072714	0.048206	0.005459
	2	0.050193	0.032318	0.004023
	1	0.021518	0.013631	0.001998

The variation of accelerations at top storey of building with time history data of Kobe earthquake, Imperial Valley earthquake and Mammoth Lake earthquake using STMD, MTMD and with damper are shown in Figs. 6-8. Also, the maximum values of accelerations at each storey level are given in Table II. It is observed that the MTMD is more effective to reduce the accelerations at top storey of building with compare to STMD. The acceleration reductions at top are observed 93.86%, 94.308% and 95.21% under Kobe, Imperial Valley and mammoth lake earthquake using MTMD. Similarly, 37.28%, 49.84% and 51.82% reduction of acceleration are recorded at the same storey using STMD. The duration of earthquake motion is considered within 10-15 s.

The base shears of building with STMD, MTMD and without dampers are shown in Figs. 9-11. The numerical values of base shears are also given in Table III, for kobe, imperial valley and mammoth earthquake. The maximum base shear reductions are observed considering MTMD with compare to STMD.

The variation of maximum displacements at storey level for different earthquake like, Kobe, Imperial Valley and Mammoth Lake using STMD, MTMD and without damper are shown in Figs. 12-14. The maximum displacements values at each level are given in Table I. From these figures, it can be seen that MTMDs are more effective with compare to STMD configuration considering 5% mass ratio and 5% damping ratio of structures.

The variations of storey drift are shown in Figs. 15-17. From these figures, it can be observed that MTMDs are more effective and robustness with compare to STMD configuration.

TABLE II
ACCELERATIONS OF BUILDING USING STMD, MTMD AND WITHOUT DAMPER FOR DIFFERENT EARTHQUAKE

Accelerations (m/s^2)				
Earthquakes	Level of floors	Without TMD	STMD	MTMD
Kobe	4	13.20116	7.00063	0.68505
	3	11.24261	5.72656	0.59938
	2	7.76059	3.8392	0.4417
	1	3.32703	1.61929	0.21941
Imperial Valley	4	12.30153	6.17018	0.70025
	3	10.47645	4.64463	0.61267
	2	7.23173	3.38377	0.4515
	1	3.1003	1.4272	0.22427
Mammoth Lake	4	11.67865	5.62623	0.55906
	3	9.94599	4.60229	0.48914
	2	6.86555	3.08547	0.36046
	1	2.94332	1.30138	0.17905

TABLE III
BASE SHEAR OF BUILDING USING STMD, MTMD AND WITHOUT DAMPERS FOR DIFFERENT

Earthquake records	Base shear (kN)		
	without TMD	STMD	MTMD
Kobe	2926.567	1849.496	296.055
Imperial Valley	2760.439	1851.716	310.868
Mammoth Lake	2930.325	1847.162	300.911

VI. CONCLUSIONS

The performance of MTMDs to mitigate the seismic vibration of structures considering real time history data is investigated in this paper. For comparative study, STMD is also installed at top of the similar structure. It is observed that maximum displacement reduces considering MTMD with compare to STMD for all real earthquake cases. Similarly, the % reductions of floor acceleration are also more for MTMD configuration with respect to STMD configuration for all real earthquake cases. Maximum reduction of base shear, inter-storey drift are also found using MTMD configuration in all cases of real earthquake. Based on the present study, it can be observed that the effectiveness and robustness of MTMD configuration is more compare to STMD configuration and overall system performance.

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Dr. Rama Debbarma is Associate Professor in Civil Engineering Department at National Institute of Technology Agartala and obtained PhD from Bengal Engineering and Science University, Shibpur, India (Presently Indian Institute of Engineering Science and Technology, Shibpur). Her area of specialization is Structural Engineering. She is a member of ASCE and Fellow, Institute of Engineers, India. She has published more than 33research papers in various International and National Journals and Conferences.

Debanjan Das is a final year M. Tech Student (Specialization: Structural Engineering), Department of Civil Engineering, National Institute of Technology Agartala. He is doing his Thesis work on Seismic response control of structures using passive control devices, like multiple tuned mass dampers, Tuned liquid dampers.