Performance of STMD and DTMDs in the Dynamic Response Control: In consideration of Non linearity in the material

[1]Deogratius A. Marenge, [2] Prof. Atul Desai, [3]Prof.Vishal B. Patel
[1]Mtech Student, [2]Professor, [3] Professor
[1]Department of Structural Engineering,
[1]BVM Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India.

Abstract: This study has been carried out to examine the performance of single and double tuned mass damper installed on top floor i.e 15th floor of the building in controlling dynamic responses of reinforced concrete structure. The building structure is subjected to four different past earthquake time history acceleration data in an order of their magnitude and duration. Non linearity in material has been considered as material property during analysis. A tuned mass damper is modeled as an additional floor on top floor and given mass ratio of 5% and assigned with link property. Nonlinear Time history analysis (Direct integration approach) has been performed in structure without TMD, with single and double TMDs using ETABS software. Performance of Single tuned mass damper (STMD) and double tuned mass damper (DTMDs) were determined by comparing responses of the structure without TMD, with single and double TMDs. Three results (displacement, Acceleration and Base shear) of the structure were considered as the performance criteria. Results indicate that tuned mass dampers are capable of decreasing structure responses, double TMDs have shown better performance than single TMD and the non-linearity in material have observed to increase the capacity of the structure to absorb more energy than linear material due to formation of plastic hinges which result in suppression of structural response.

***IndexTerms* – Displacement, Acceleration, Base shear, Single Tuned Mass Damper, Double Tuned Mass Damper.**

I. INTRODUCTION

Most of high rise buildings are constructed with relatively light weight materials to reduce the weight of structure and economize the cost of foundation. some of these building have been constructed in area which are prone to earthquake. During Earthquake these buildings are displaced relatively high and vibrate with relatively high frequency which are threat to both structural life, nonstructural elements in a building and comfortability of building users due to their flexibility and low natural damping system inherited from the construction materials.

The law of conservation of energy is applied worldwide, “the energy cannot be created or destroyed but can be transformed from one form to another”, in this case the energy from earthquake is naturally dissipated through the building natural damping system like friction in joints, internal stressing and minor plastic deformation. Also some various Artificial techniques have been adopted to dissipate the Earthquake forces in such a way that the threat to the structure and occupants are minimized by reducing the frequency of vibration of the building. Many techniques have been adopted since two decades ago, on vibration controlling mechanism which are Passive, Active, semi active and hybrid. Selection of type of vibration control device to be used depend on efficiency, Cost (Initial, Operating and maintenance), Compactness and safety.

A Tuned mass damper (TMD) is a system for hampering the amplitude of vibrating structure by transferring into the attached secondary system which will finally reducing the dynamic response of the main structure and ultimately reduce the damages which would affect the primary structure.

TMD has been widely adopted for vibration control in machine-driven systems. Currently they are adopted to reduce dynamic response of civil engineering structures like tall building, bridges etc. and they have displayed positive contribution in many civil engineering structures applications.

The attached secondary system considered, has the natural frequency, which is the function of its mass and stiffness, the frequency is tuned to that of the primary structure. When the structure vibrates with a certain frequency, TMD will vibrate out of phase with the direction of structural motion and decreases its dynamic response hence reduces the damage. Thus, the surplus energy that is developed in the structure can be transmitted to the attached secondary system and is degenerate by the dashpot due to relative motion between them at a later time. Mass of the secondary system varies from 1-10% of the main structural mass. In case of high magnitude and random earthquake with high frequency of vibration, more than one Tune mass damper has been adopted to control dynamic response of high raised structure in which more than one TMD’s can be installed along the height of structure and tuned to different frequencies.

PRINCIPLES OF TUNED MASS DAMPER (TMD)

A Tuned Mass Damper (TMD) operates as a passive control device. It is commonly used to decrease the amplitude of structural and mechanical vibrations. It consists of three main components which are, a lumped mass, a spring and a viscous damper. These components are attached to the primary (Main) structure and tuned to frequency of that main structure to decrease unwanted vibration. During vibration of the Main structure, the Lumped mass of TMD moves relative to the main structure and hence suppress the vibration. This mass is attached to the structural system with a spring and damper in parallel connection.

Single Tuned Mass Dampers (STMD)

The idea of using of Single Tuned Mass Damper (STMD) was initiated by **Frahm (1909)**. He adopted spring absorber to control rolling motion in ships, and un damped mass spring absorber showed ability to suppress the amplitude of the main system nearly to zero for a single frequency. Thereafter the idea of Frahm was modified by **Ormondroyd and Den Hartog (1928).** They develop damped vibration absorber for widely frequency vibration. Furthermore, they develop the system of invariant points that has evolved as the path for analytical optimal solution, which could control the response of the main structure and the developed system.

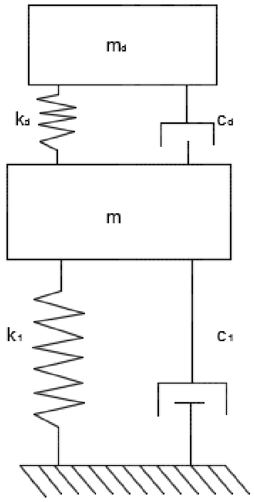


Fig. 1: Single tuned mass damper

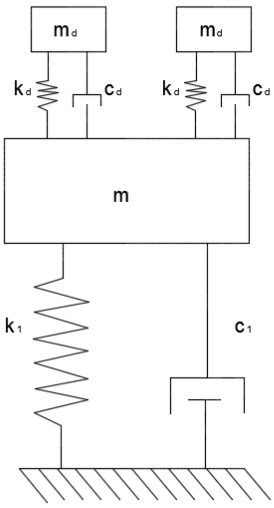


Fig. 2: Multiple tuned mass damper system

Multiple Tuned Mass Dampers (MTMD)

Multiple Tuned Mass Dampers (MTMD) contains more than one lumped mass dampers. In this case TMDs are fixed at different levels of main structure to regulate multiple mode of vibration.

Many studies have been conducted on the application of multi tuned mass damper for vibration control for single degree of freedom system by **Xu and Igusa (1991).** Researchers have proved that MTDS with dispersed natural frequency perform better than single TMD. **Kareem and Kline (1995)** also develop study on performance of MTMD under random loads.

Thereafter, **Chen and Wu (2001)** studied MTMD installed in structures considered as multi degree of freedom system subjected to seismic loads, The MTMD were designed and tuned to numerous modes of structure vibration. Dampers were placed in the location of maximum modes, their number are subjected to the number of available modes of vibration of structure.

The basic arrangement of a multiple tuned mass damper includes number of TMD's connected to the main structure as shown in Fig.2.

2. OBJECTIVE

The main objective of this study is to determine the performance of STMD and DTMDs in 15 storey reinforced concrete structure by considering non linearity in material of structure.

The following are the specific Objectives

i. To perform nonlinear time history analysis for 15 storey RC building with and without TMD
ii. To determine Displacement, Acceleration, Base Shear and Time period of RC building with and without TMD
iii. To compare the performance of STMD and DTMDs installed in structure against RC structure without TMD.

3. LITERATURE REVIEW

In this section contain review of various past studies relating to response control system.

Sakr, T.A [7] Proposed the use of partial floor loads as multiple tuned mass dampers. His idea was based on utilization of portion of floor loads from self-weight, finishes and partition loads as Tuned mass damper. This concept helped to avoid installation of large weight of TMDs as some of the portion of TMD'S weight can be replaced by floor weight. He used mathematical model to study the response characteristics of multi-storey building with multiple TMD. Three different earthquake forces and wind motions with various frequency as dynamic loads were applied to study the effect of design parameters like the ratio of the floor load used, number of floors used, and excitation characteristics for low, mid and high rise building. He concluded that, multiple-story TMDs considerably decreases the drift, acceleration, and force response of all observed structural buildings subjected to sinusoidal dynamic loads and as the mass percentage and number of floors used as TMDs increases, the response control of all type of sinusoidal loads increases.

Mohebbi, M and Joghataie, A [5] Carried out study on Designing optimal tuned mass dampers for nonlinear frame. They developed genetic algorism to determine optimum parameters of TMD which could decrease the response of structure. They observed that the obtained parameters had reduced the structural response i.e floor drift has been reduced and accumulated hysteretic energy. Also they found that effectiveness of TMD depend on the mass ratio of TMD, Maximum TMD stroke length and TMD design earthquake.

Makino.A et all [4] Carried out study on seismic vibration control by treating the whole part of top floor (isolated floor) as mass tuned damper. During seismic analysis, the building with 162m height was considered, with 43 storeys above the ground, an artificial earthquake wave was applied, natural period was tuned to decrease the storey drift. The building was assumed to be elastic. The optimum frequency of the mass damper was 3.8 cycle/ sec., same as natural frequency of the building. The results show that, if the building is assumed to be elasto-plastic, the damper becomes the most effective when the frequency was tuned to about 8.0 cycle/sec. And with the mass damper, the maximum story drift of the building is reduced by about 20%.

Heuer. R, and Adam. C [2] Carried out study to examine the benefits of several passive control systems of structures subjected to seismic excitations considering nonlinear response. They reviewed past research studies carried out by different Authors. They observed that for effectiveness of TMD, accurate tuning of frequency and damping was vital in response control of structures, otherwise, Multiple TMDs could be employed in scattered frequency where the natural frequency was above the targeted frequency. They concluded that the use of passive control system (TMD) was prevailing in controlling response because it did not require power in their operation and also TMDs are flexible since the nonlinear spring could be incorporated in TMD to suppress nonlinear response.

Murudi. M.M and Mane. S.S [6] performed seismic effectiveness of mass tuned damper for different ground motion parameters. A single degree of freedom structure was considered with its natural frequency and damping, then TMD model was attached to the structure and their combination act as two degree of freedom system. Data from various real recorded seismic ground vibration records and created seismic ground vibration were used in the analysis by using minimax optimization technique. They found that TMD was capable of reducing earthquake response of lightly damped structure for both real ground recorded vibration and the created vibration, Furthermore the TMD's effectiveness is influenced by tuned frequency, bandwidth and duration of strong seismic vibration, yet the effectiveness of TMD is not affected by the intensity of seismic ground vibration.

Chen and Wu [1] Studied the Optimal Placement of Multiple Tune Mass Dampers for Seismic Structures. They considered six story building structure to study the effects of single TMD in modal response, followed by multistage and multimodal TMDs. Dampers were placed at locations of maximum modes of the six storied building and time history analysis were used to determine the effectiveness of the TMD in different stages. The results showed. that multiple TMD perform much better than single TMD in response reduction of the uncontrolled structure by 10–25% extra, also results show that, the multiple TMDs weighs 3% of total structural weights is sufficiently enough to suppress the floor response up to 40%. The Multiple TMDs are capable to decrease peak acceleration due to impulsive excitation while Single TMDs are incapable.

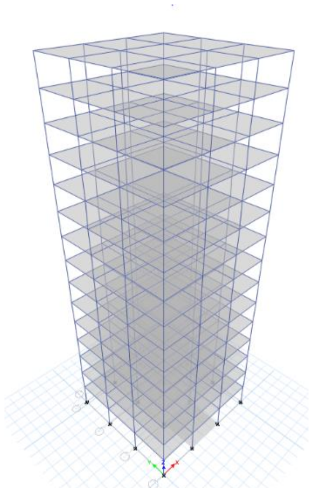
4. RESEARCH METHODOLOGY

A tuned mass damper is modeled as an addition floor on top floor and given mass ratio of 5% and assigned with link property. Steel is used as a support of mass because it's more prone to vibration. STMD is placed centrically and DTMD is arranged in parallel. A square plan of building is selected for analysis and assumed that no torsion is experienced. Slab is assumed to be rigid.

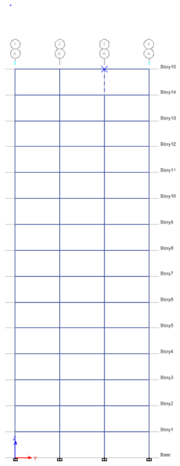
Nonlinear Time history analysis (Direct integration approach) is performed in structure without TMD, with single and double TMDs using ETABS software. Performance of STMD and DTMDs are determined by comparing responses of the structure without TMD, with single and double

Model

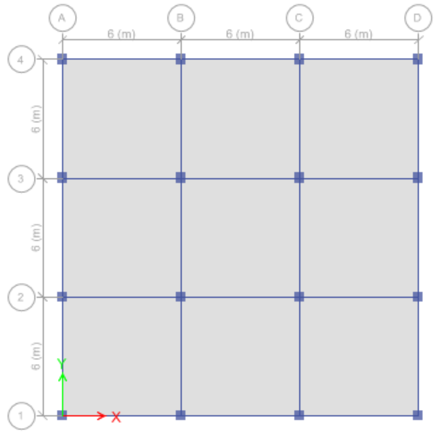
A (G+15) Storey RC building subjected to time history earthquake data from Loma Prieta (1989), Bhuj (2001), El Centro, (1940) and Kobe earthquake (1995) have been considered. In this regard, ETABS software have been considered as tool to perform Nonlinear time history analysis. The square plan of building with and without tuned mass damper has been considered to carry out the study.



3D MODEL



ELEVATION



PLAN

Geometric and material properties of the 3D frame, Zonal data and loading are given below.
Total height of the building = 52.5 m
Height of each floor = 3.5 m
Each bay width = 6 m
Number of storey =15
Number of bay =3
Size of beam = (0.25×0.45) m
Size of column = (0.5×0.5) m
Grade of concrete = M25
Modulus of elasticity = 25×103 KN/m2
Total mass of the building = 4473163.53 kg
Live load=3.5KN/m^2
Finishes=1.5KN/m^2
Frame uniform load=4 KN/m
Importance factor (I) = 1
Soil Type= 2 (Medium)
Seismic zone= II
Zone Factor= 0.24
Response reduction factor= 5

5. RESULTS AND DISCUSSION

Table 5.1: Comparison of maximum displacement at 15^{th} story of a reinforced concrete structural building with and without tuned mass damper for a mass ratio of 5%

Vibration type	Structural Modal without TMD(M1) (mm)	Structural Modal with Single TMD (M2) (mm)	Structural Modal with double TMDs (M3) (mm)	% Decrease (M1-M2)/M1	% Decrease (M1-M3)/M1
Bhuj Earthquake	75.92	66.58	44.61	12.30	41.24
El-Centro Earthquake	63.73	44.77	31.10	29.76	51.20
Kobe Earthquake	43.24	33.67	11.07	22.12	74.40
Loma Earthquake	75.45	66.68	46.46	11.62	38.42

Table 5.2: Comparison of maximum Acceleration (mm/sec^2) at 15^{th} story of a reinforced concrete structural building with and without tuned mass damper for a mass ratio of 5%

Vibration type	Structural Modal without TMD(M1)	Structural Modal with Single TMD (M2)	Structural Modal with double TMDs (M3)	% Decrease (M1-M2)/M1	% Decrease (M1-M3)/M1
Bhuj Earthquake	205.43	177.38	96.56	13.65	52.99
El-Centro Earthquake	468.48	367.41	267.37	21.57	42.93
Kobe Earthquake	1025.83	893.05	571.84	12.94	44.25
Loma Earthquake	298.32	216.45	192.51	27.44	35.47

Table 5.3: Comparison of maximum base shear (KN) of a reinforced concrete structural building with and without tuned mass damper for a mass ratio of 5%

Vibration type	Structural Modal without TMD(M1) (KN)	Structural Modal with Single TMD (M2) (KN)	Structural Modal with double TMDs (M3) (KN)	% Decrease (M1-M2)/M1	% Decrease (M1-M3)/M1
Bhuj Earthquake	731.46	631.87	507.72	13.62	30.59
El-Centro Earthquake	711.25	606.62	583.62	14.71	17.94
Kobe Earthquake	668.59	572.22	514.85	14.41	22.99
Loma Earthquake	731.67	630.12	508.13	13.88	30.55

Table 5.4: Comparison of Maximum Time period (sec) of a reinforced concrete structural building with and without tuned mass damper for a mass ratio of 5%

Vibration type	Structural Modal without TMD(M1) (sec)	Structural Modal with Single TMD (M2) (sec)	Structural Modal with double TMD (M3) (sec)	% Increase (M1-M2)/M1	% Increase (M1-M3)/M1
Bhuj Earthquake	3.48	3.66	3.83	5.17	10.06
El-Centro Earthquake	3.48	3.66	3.83	5.17	10.06
Kobe Earthquake	3.48	3.66	3.83	5.17	10.06
Loma Earthquake	3.48	3.66	3.83	5.17	10.06

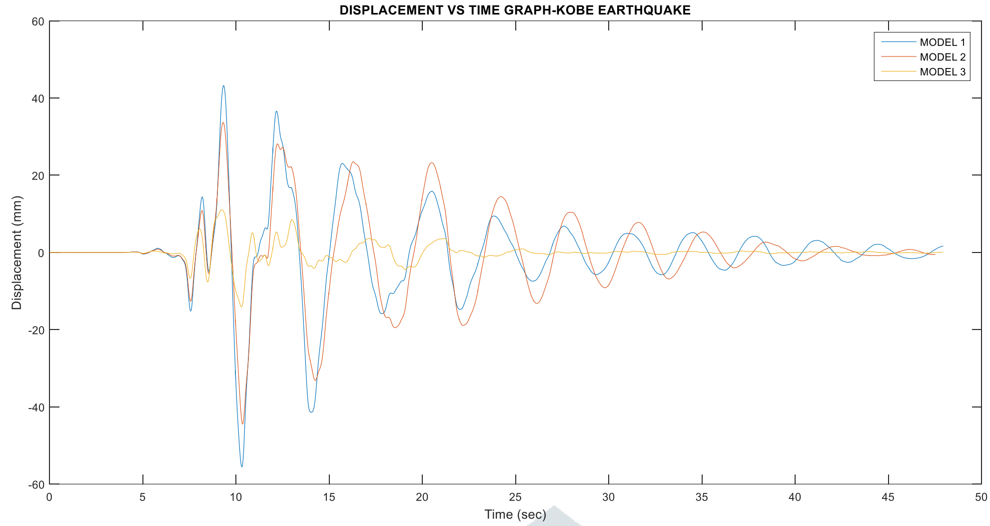


Figure 1a: Comparison of displacements of models with Kobe earthquake

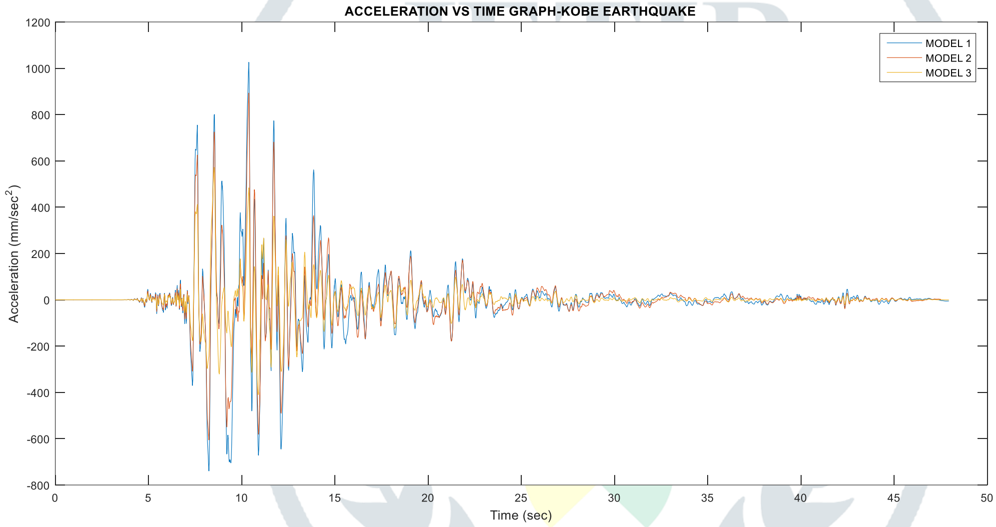


Figure 1b: Comparison of acceleration of models with Kobe earthquake

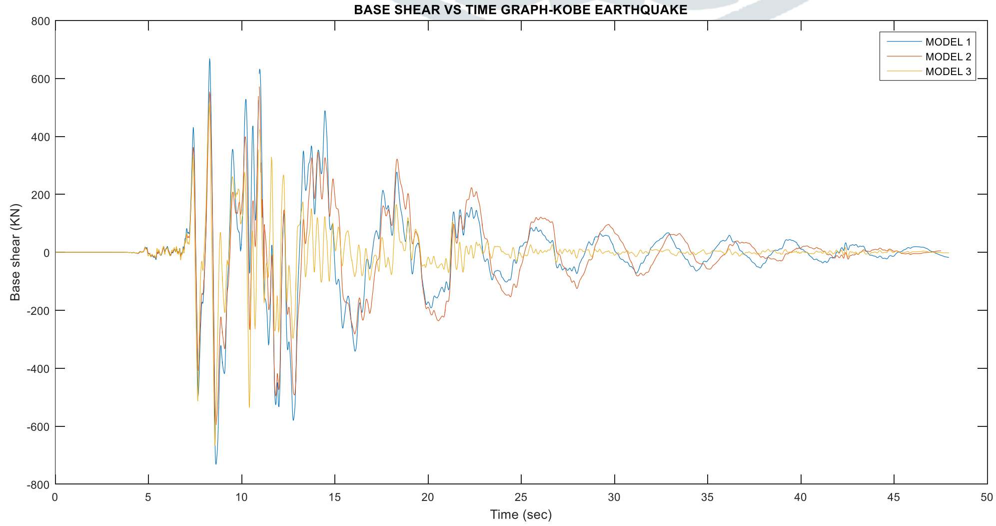


Figure 1c: Comparison of Base shear of models with Kobe earthquake

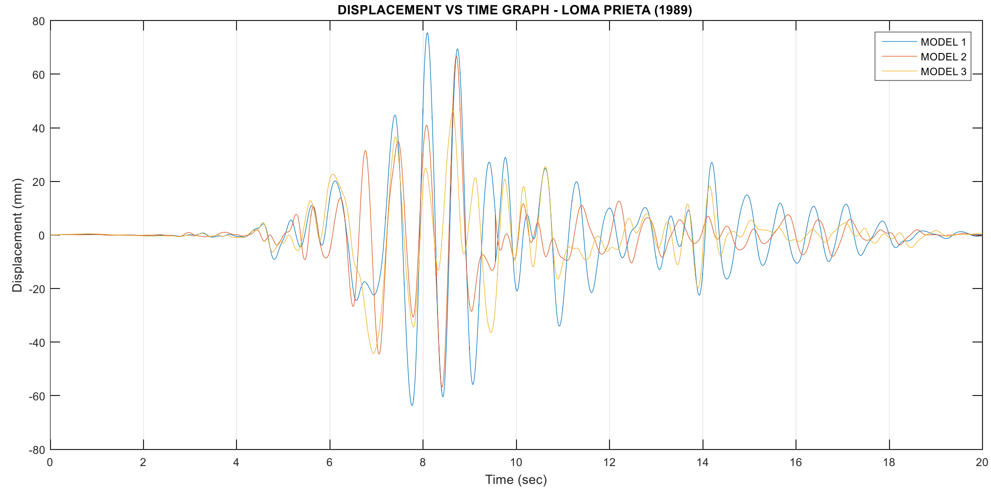


Figure 2a: Comparison of displacements of models with Loma Prieta earthquake

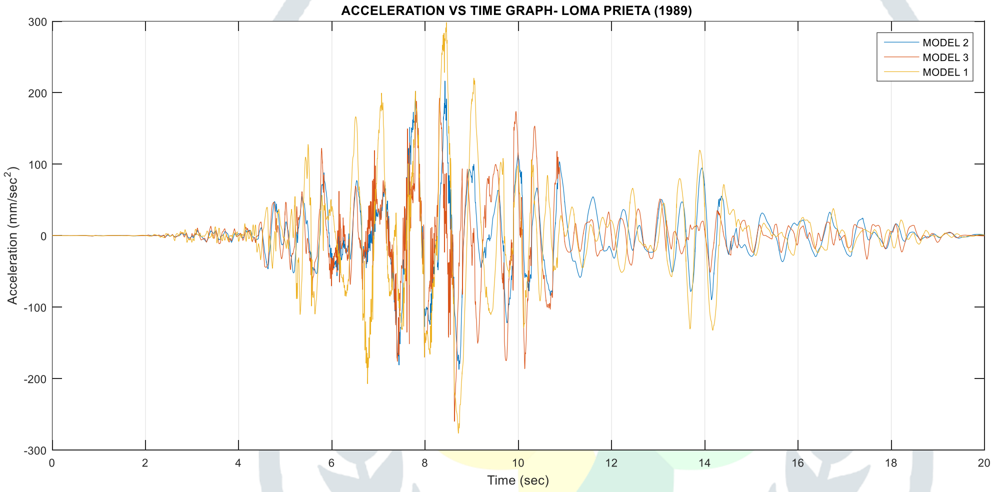


Figure 2b: Comparison of acceleration of models with Loma Prieta earthquake

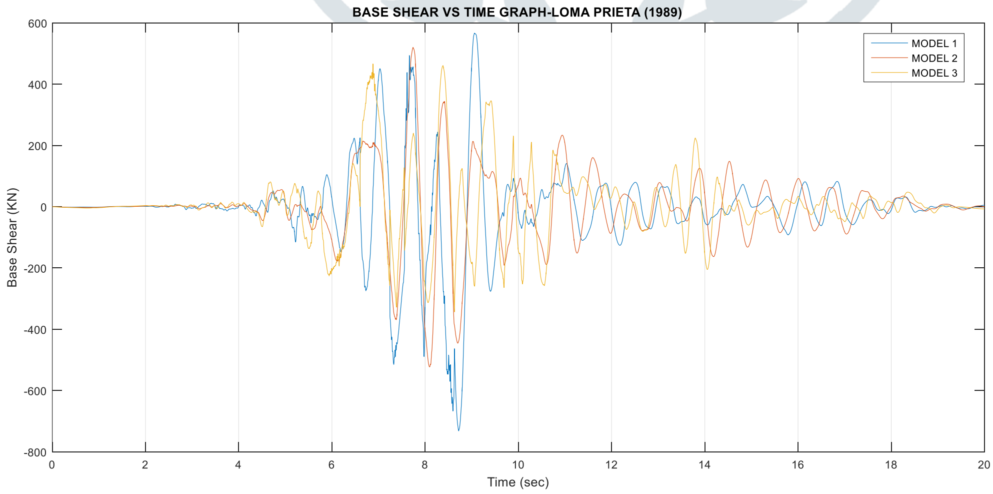


Figure 2c: Comparison of Base shear of models with Loma Prieta earthquake

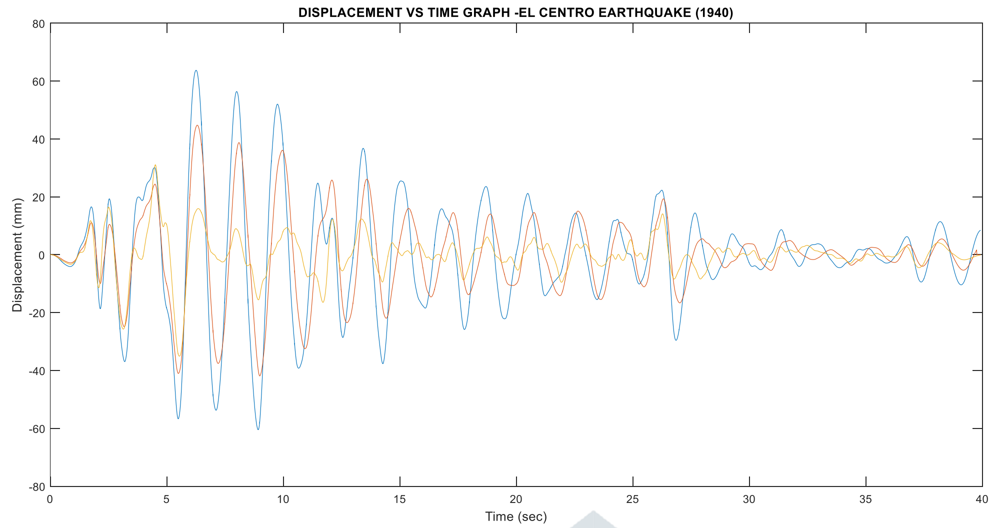


Figure 3a: Comparison of displacements of models with El Centro earthquake

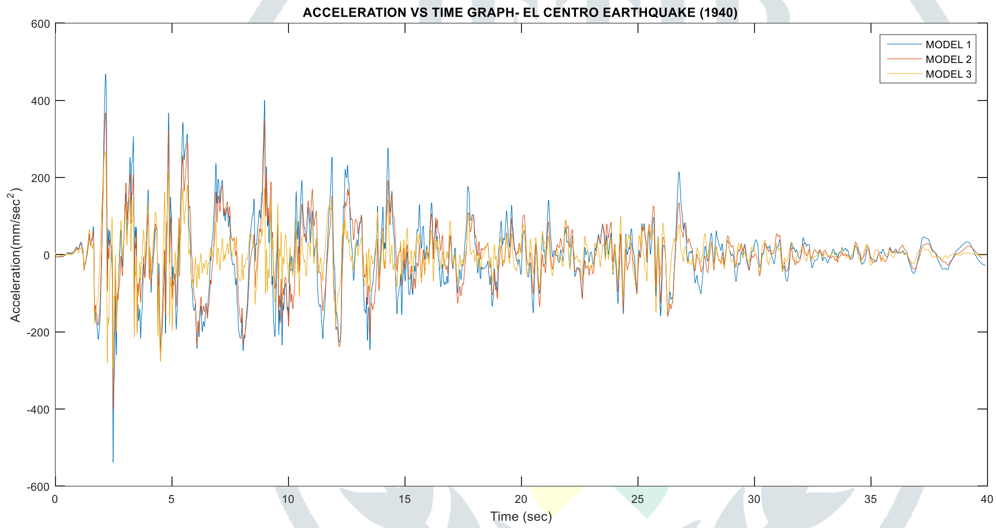


Figure 3b: Comparison of acceleration of models with El Centro earthquake

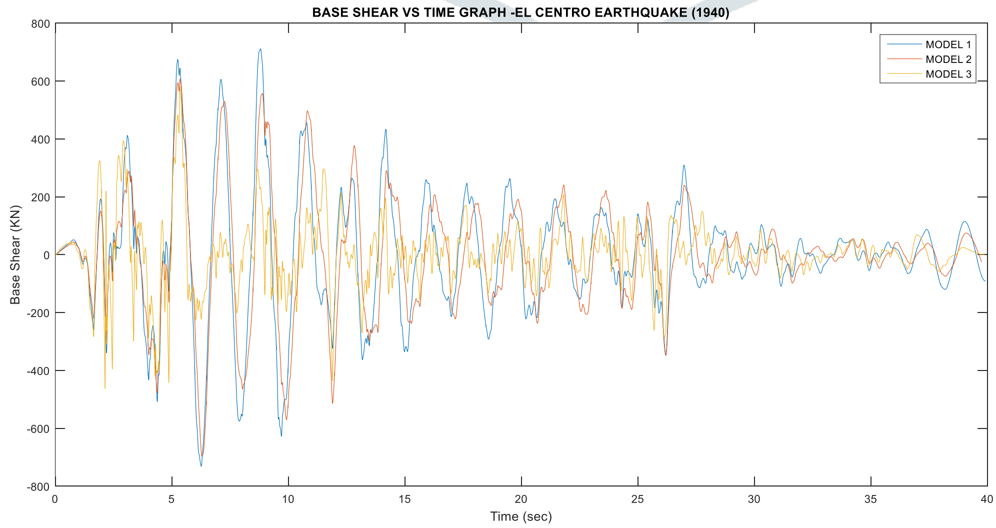


Figure 3c: Comparison of Base shear of models with El Centro earthquake

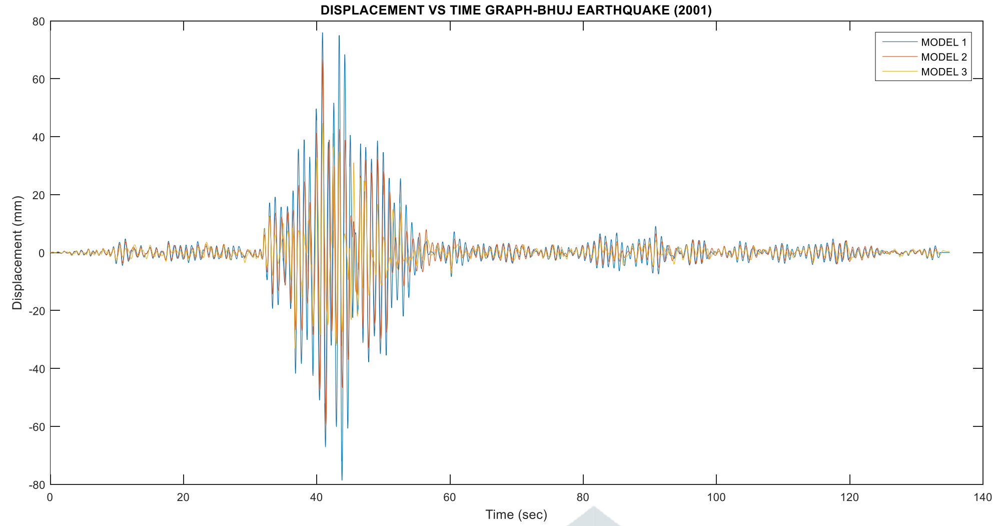


Figure 4a: Comparison of displacements of models with Bhuji earthquake

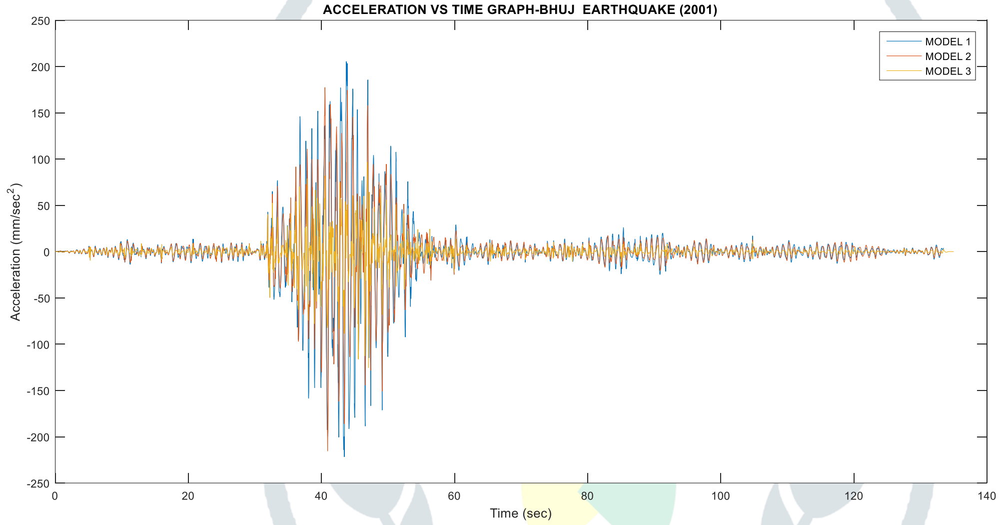


Figure 4b: Comparison of accelerations of models with Bhuji earthquake

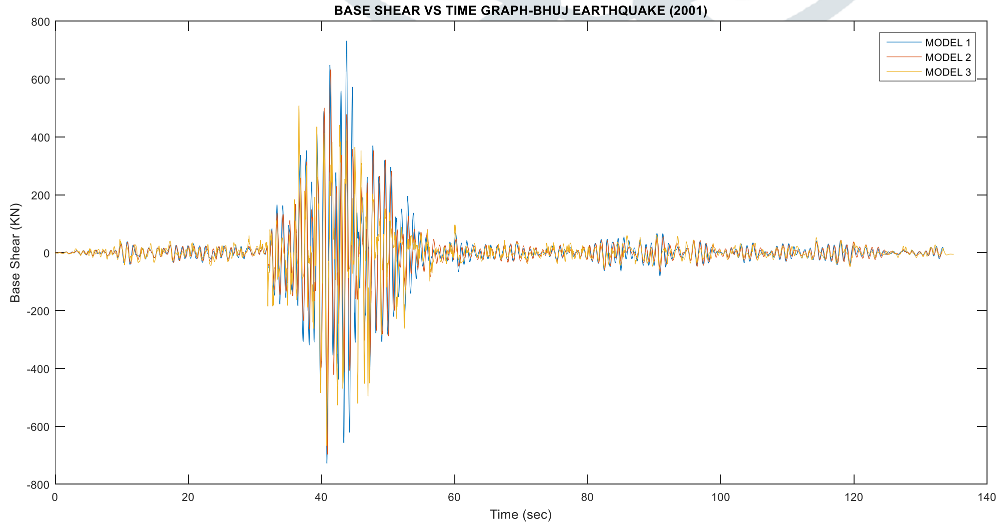


Figure 4c: Comparison of Base shear of models with Bhuji earthquake

Discussion

i. Figure 1(a) present the plots of three modals (M1, M2 and M3) of displacements on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak displacement of M1 on top floor have reduced to 22.12% and 74.4% in M2 and M3 respectively.

ii. Figure 1(b) present the plots of three modals (M1, M2 and M3) of accelerations on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak accelerations of M1 on top floor have reduced to 12.94 % and 44.46% in M2 and M3 respectively.

iii. Figure 1(c) present the plots of three modals (M1, M2 and M3) of base shear of the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak base shear of M1 have reduced to 14.41 % and 22.99% in M2 and M3 respectively.

iv. Figure 2(a) present the plots of three modals (M1, M2 and M3) of displacements on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak displacement of M1 on top floor have reduced to 11.35% and 28.68% in M2 and M3 respectively.

v. Figure 2(b) present the plots of three modals (M1, M2 and M3) of accelerations on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak accelerations of M1 on top floor have reduced to 21.1% and 66.54% in M2 and M3 respectively.

vi. Figure 2(c) present the plots of three modals (M1, M2 and M3) of base shear of the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak base shear of M1 have reduced to 15.67 % and 44.44% in M2 and M3 respectively.

vii. Figure 3a present plots of three modals (M1, M2 and M3) of displacements on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak displacement of M1 on top floor have reduced to 29.76% and 51.20% in M2 and M3 respectively.

viii. Figure 3(b) present the plots of three modals (M1, M2 and M3) of accelerations on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak accelerations of M1 on top floor have reduced to 21.57% and 42.93% in M2 and M3 respectively.

ix. Figure 3(c) present the plots of three modals (M1, M2 and M3) of base shear of the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak base shear of M1 have reduced to 14.71% and 17.94% in M2 and M3 respectively.

x. Figure 4a present plots of three modals (M1, M2 and M3) of displacements on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak displacement of M1 on top floor have reduced to 12.3% and 41.24% in M2 and M3 respectively.

xi. Figure 4(b) present the plots of three modals (M1, M2 and M3) of accelerations on top floor for the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak accelerations of M1 on top floor have reduced to 13.65% and 52.99% in M2 and M3 respectively.

xii. Figure 4(c) present the plots of three modals (M1, M2 and M3) of base shear of the building without TMD, with single TMD and double TMDs respectively. It is observed that the peak base shear of M1 have reduced to 13.61% and 30.59% in M2 and M3 respectively.

6. CONCLUSION

On the basis of present analysis done on 15 storey reinforced concrete building and theoretical knowledge in response control system, the following conclusions can be drawn:

1. Tuned mass damper has shown capability of reducing response of the structure.
2. Double tuned mass damper perform better than single tuned mass damper placed at the top floor.
3. Application of both single and double tuned mass damper has proved to reduce floor displacement, acceleration and base shear.
4. Through consideration of non-linearity in materials damping of structure has increased due to formation of plastic hinges.
5. With the application of TMDs fundamental time period of structure has increased. With different earthquake loading; % of increase of time period remain the same without depending on the nature of earthquake; this implies that, time period depends on the geometric property of the building and not nature of earthquake.

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