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# Study of Tuned Mass Damper as Vibration Controller in Frame Structure

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## ABSTRACT

Current trend in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. These structures are flexible and constructed as light as possible, which have low value of damping. This increases failure possibilities and also problems from serviceability point of view. Current trends use several techniques to reduce wind and earthquake induced structural vibration, out of the several techniques available for vibration control, concept of using TMD (Tuned mass damper) is a newer one. This study was made to study the effectiveness of using TMD for controlling vibration of structure. Passive tuned mass damper (TMD) is widely used to control structural vibration under wind load but its effectiveness to reduce earthquake induced vibration is an emerging technique. Total two types of models, i.e., 3D frame with single TMD and 3D frame with double TMD are considered. Total six numbers of loading conditions are considered named sinusoidal ground acceleration, EW component of 1940 El-Centro earthquake (PGA=0.2144g), compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil (PGA=1.0g), Sakaria earthquake (PGA=1.238g), The Landers earthquake (1992) (PGA=1.029g) and Mexico earthquake(1995)(PGA=1.24g) for time history analysis of considered model. The effectiveness of single TMD to reduce frame vibration is studied for variation of mass ratio of TMD to 3D frame. Also the effect of double tuned mass damper on the 3D frame response is studied for variation of mass ratio of damper. From the study it is found that effectiveness of TMD increases with increase in mass ratio. Use of double TMD is much more effective than single TMD of same mass ratio for vibration mitigation under earthquake as well as sinusoidal acceleration.

**Keywords:** Lighter structures, 3D frame, Tuned mass damper, Damping, Earthquake, Vibration, SAP2000, Damper

## I. INTRODUCTION

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. Vibration control is essential for machinery, space shuttle, aeroplane, ship floating in water. With the modernization of engineering the vibration mitigation technique has find a way to civil engineering and infrastructure field.

Now-a-days innumerable high rise building has been constructed all over the world and the number is increasing day by day. This is not only due to concern over high density of population in the cities, commercial zones and space saving but also to establish country land marks and to prove that their countries are up to the standards. As the seismic load acting on a structure is a function of the self-weight of the structure these structures are made comparatively light and flexible which have relatively low natural damping. Results make the structures more vibration prone under wind, earthquake loading. In many cases this type of large displacements may not be a threat to integrity of the structure but steady state of vibration can cause considerable discomfort and even illness to the building occupant.

In every field in the world conservation of energy is followed. If the energy imposed on the structure by wind and earthquake load is fully dissipated in some way the structure will vibrate less. Every structure naturally releases some energy through various mechanisms such as internal stressing, rubbing, and plastic deformation. So new generation high rise building is equipped with artificial damping device for vibration control through energy dissipation. The various vibration control methods include passive, active, semi-active, hybrid. Various factors that affect the selection of a particular type of vibration control device are efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety.

A Tuned mass damper (TMD) is a passive damping system 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. Now a days TMD theory has been adopted to reduce vibrations of tall buildings and other civil engineering structures. The secondary mass system is designed to have the natural frequency, which is depended on its mass and stiffness, tuned to that of the primary structure. When that particular frequency of the structure gets excited the TMD will resonate out of phase with the structural motion and reduces its response. Then, the excess energy that is built up in the structure can be transferred to a secondary mass and is dissipated by the dashpot due to relative motion between them at a later time. Mass of the secondary system varies from 1-10% of the structural mass. As a particular earthquake contains a large number of frequency content now a days multiple tuned mass dampers (MTMD) has been used to control earthquake induced motion of high rise structure where the more than one TMD is tuned to different unfavourable structural frequency.

## II. METHODS AND MATERIAL

A large numbers of technique have been tried to produce better control against wind and earthquake excitation. These can be classified into four broad categories: passive control, active control, semi-active control and hybrid control. Each of these will be discussed in following section.

### A. **Passive control**

The most mechanically simple set of control schemes is enclosed in the passive control category, which has been widely accepted for civil engineering application. Housner et al. have both provided brief overviews on structural control, including proper definitions for the various types of control practically implemented in structures. According to them 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.

The main purpose of these systems is to efficiently dissipate vibrational energy, and the various methods of achieving this can be categorized in two ways. The first method includes converting kinetic energy directly to heat, such as through the yielding of metals, the deformation of viscoelastic solids and fluids, or the implementation of friction sliders. The second method works on transferring energy among two or more of the vibrational modes of the building, generally achieved by adding a supplemental oscillator that absorbs the vibrations of the primary structure. Tuned mass damper, Tuned liquid damper, Base isolation are example of passive system.

### B. **Active control**

Active control is a relatively upcoming subfield of structural engineering. It assures improved response to passive systems at the cost of energy and more complex systems. 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. In order to maximize the performance of an active system, the actuator forces must be prescribed in real-time base on the inputs of the sensors. The direction and magnitude of these forces can be assigned in the variety of ways, all of which have their roots in the diverse and mathematically rich field of control engineering.

### C. **Semi-active control**

Semi active control performed on the benefits of active control and the reliability of passive control, which makes it a much more appealing alternative to traditional control scheme in civil structures.

Semi active control systems act on the same principle of active control system but they differ in that their external energy 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 viewed 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. That means, by changing the properties of these devices, using only nominal power the response of the system may be favourably modified. 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.

### D. **Tuned Mass Damper**

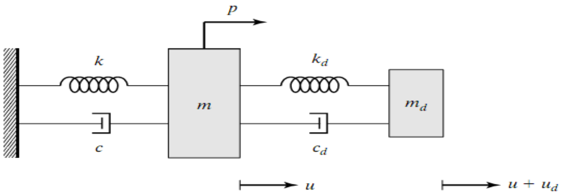

**Figure 1:** Tuned Mass Damper

A TMD is an inertial mass attached to the building location with maximum motion (generally near the top), through a properly tuned spring and damping element. Generally viscous and viscoelastic dampers are used. TMDs provide a frequency dependent hysteresis, which increases damping in the frame structure attached to it in order to reduce its motion. The robustness is determined by their dynamic characteristics, stroke and the amount of added mass they employ. The additional damping introduced by the TMD is also dependent on the ratio of the damper mass to the effective mass of the building in a particular mode vibration. TMDs weight is varied between 0.25%-1.0% of the building's weight in the fundamental mode.

The frequency of a TMD is tuned to a particular structural frequency when that frequency is excited the TMD will resonate out of phase with frame motion and reduces its response.

Often for better response control multiple-damper configurations (MDCs) which consist of several dampers placed in parallel with distributed natural frequencies around the control tuning frequency is used. For the same total mass, a multiple mass damper can significantly increase the equivalent damping introduced to the system.

## III. RESULTS AND DISCUSSION

### A. RANDOM EARTHQUAKE GROUND ACCELEROGRAM

Total five numbers of past random accelerogram are considering in this report as named:

(a) EW component of 1940 El-Centro earthquake (PGA=0.2144g)
(b) Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil (PGA=1.0g)
(c) Sakaria earthquake (PGA=1.238g)
(d) The Landers earthquake (1992) (PGA=1.029g)
(e) Mexico earthquake(1995) (PGA.1.24g) are taken into consideration for time history analysis of the proposed 3D frame building model without and with Single and double TMD .

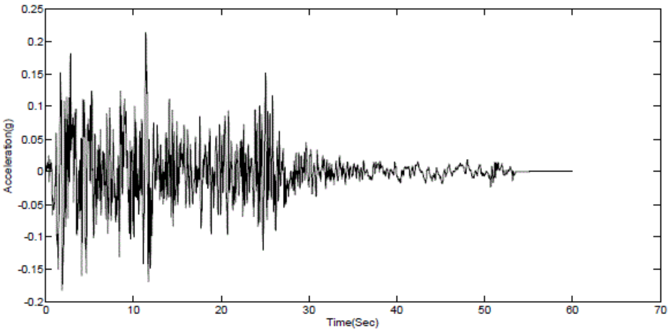

**Figure 2:** EW component of El-Centro earthquake accelerogram (1940) (PGA=0.2144g).

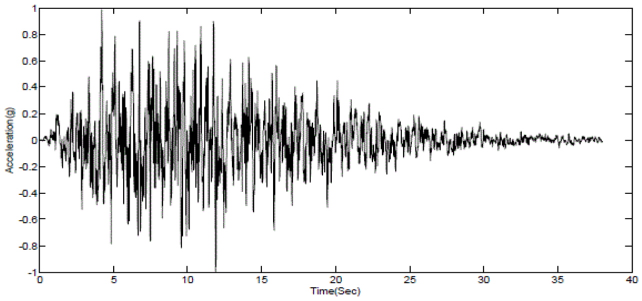

**Figure 3:** Compatible Earthquake ground acceleration time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil. (PGA=1.0g).

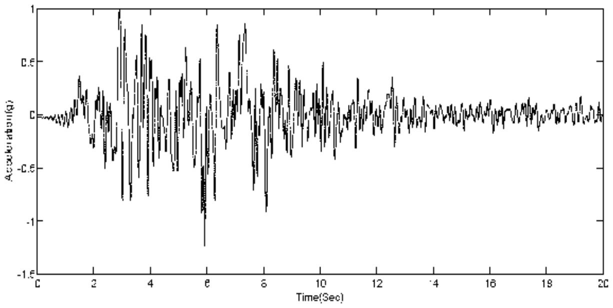

**Figure 4:** Sakaria earthquake accelerogram. (PGA=1.238g).

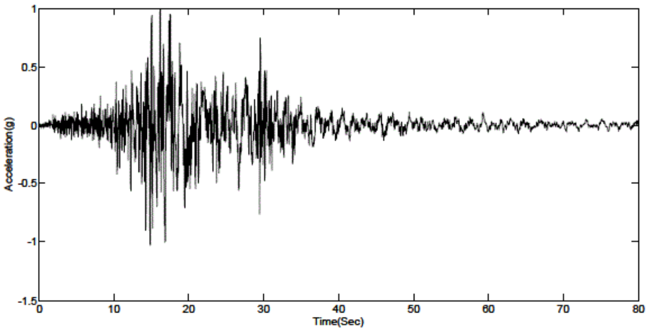

**Figure 5:** The Landers earthquake accelerogram (1992). (PGA=1.029g).

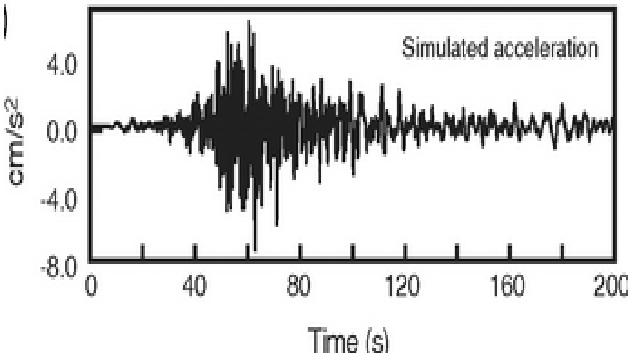

**Figure 6:** Earthquake Mexico(1995). (PGA=1.24g)

## B. LINEAR TIME HISTORY ANALYSIS OF 3D FRAME WITH AND WITHOUT SINGLE TMD

The effectiveness of single tuned mass damper for vibration control is studied by linear time history analysis of the frame building under a sinusoidal load and the five numbers past earthquake data. The damping ratio of the frame building as well as damper is taken as 0.05 for every mode. In each case fundamental frequency of the building without TMD is tuned to the frequency of the damper. The response is calculated in terms of displacement at the 10th floor.

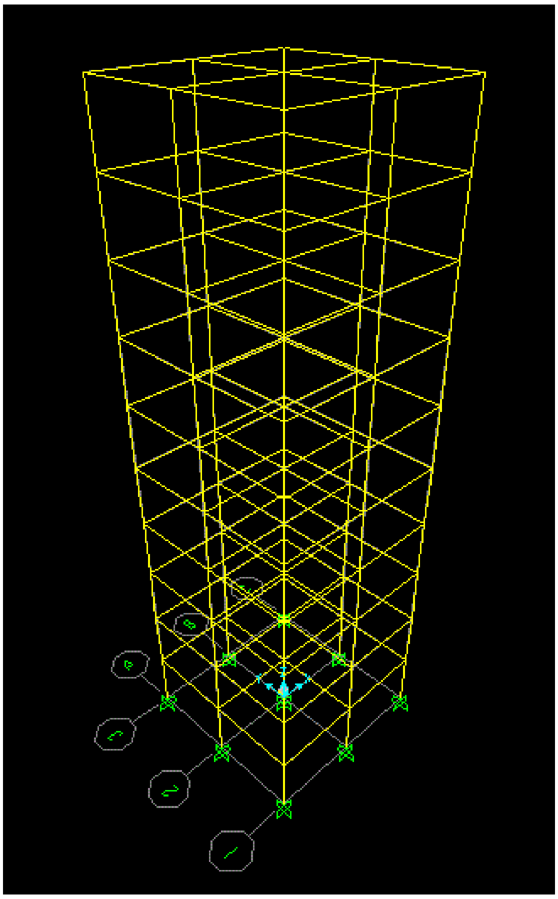

**Figure 7 :** 3D frame model without TMD.

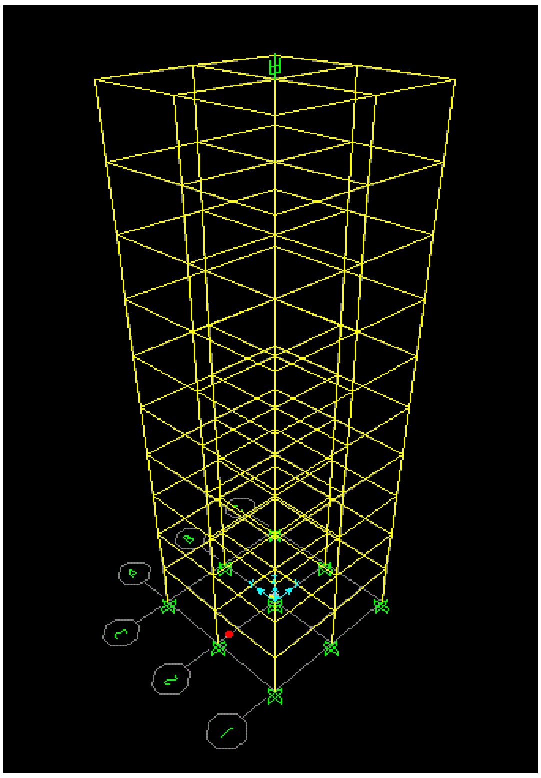

**Figure 8 :** 3D frame model with one TMD.

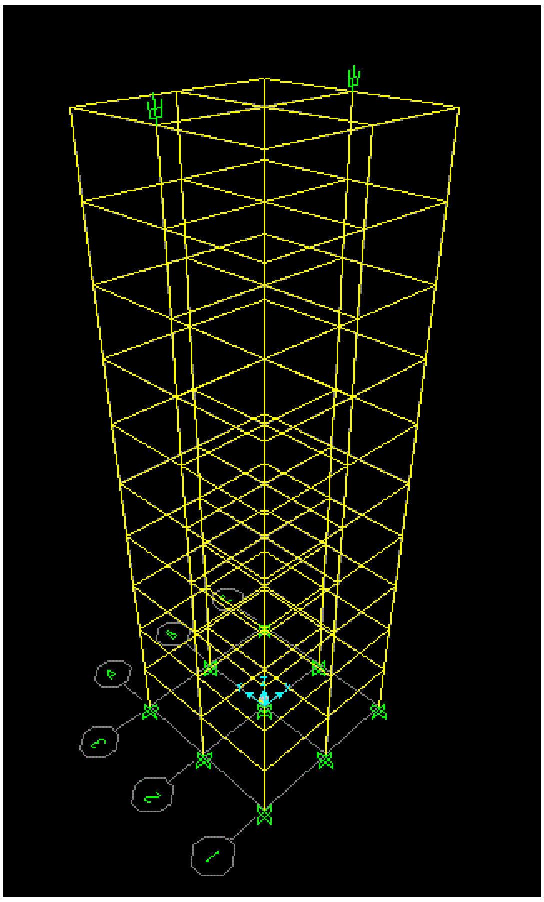

**Figure 9 :** 3D frame model with two TMD.

## C. Response of the 3D frame with variation of TMD mass ratio

### 1. Sinusoidal Acceleration

Two different mass ratios of 0.05 and 0.1 are taken in analysis. Frame building is subjected to sinusoidal acceleration Ä=Amaxsin(ω.t) at ground. Where, Amax and ω are the maximum amplitude of acceleration and frequency of the sinusoidal acceleration respectively. The parameters Amax and ω are 0.1 m/s2 and 3.21 rad/s (considering resonance condition) respectively.

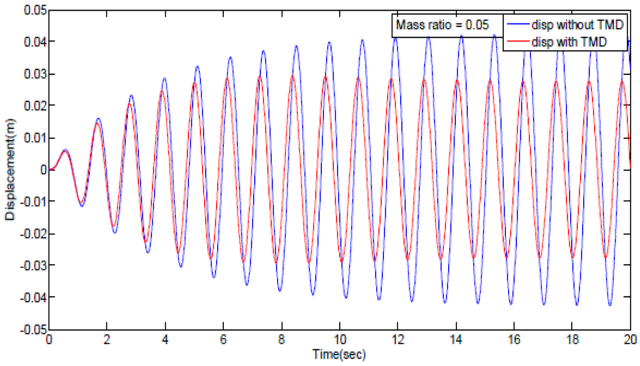

Figure 10: Mass ratio 0.05 (Displacement of the 3D frame with and without single TMD at 10th floor under sinusoidal ground acceleration.)

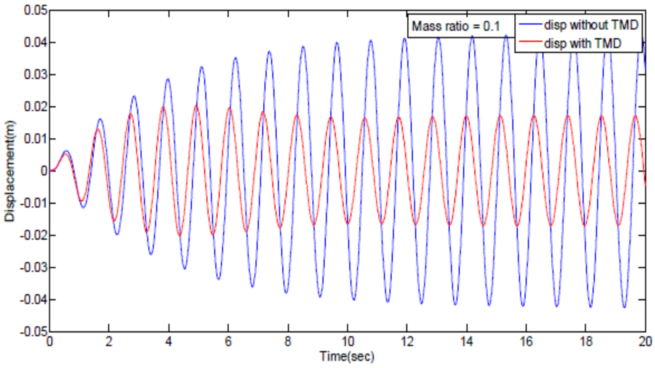

Figure 11: Mass ratio 0.1 (Displacement of the 3D frame with and without single TMD at 10th floor under sinusoidal ground acceleration.)

### 2. Random earthquake ground acceleration

Here response of the 3D frame (in term of displacement) is calculated with two different mass ratio of 0.05 and 0.1 for the TMD under the above mentioned random earthquake ground acceleration.

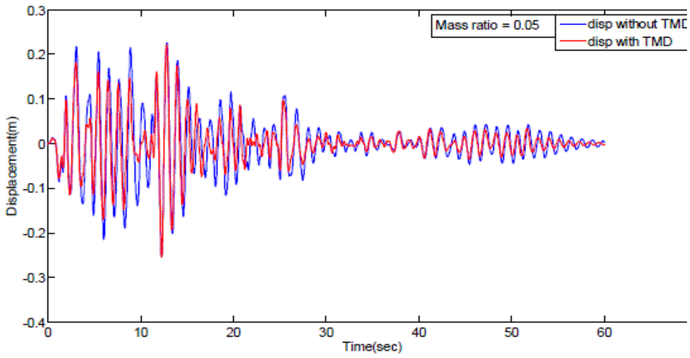

**Figure 12:** Mass ratio 0.05 (Displacement of the 3D frame with and without single TMD at 10th floor under EW component of 1940 El-Centro earthquake)

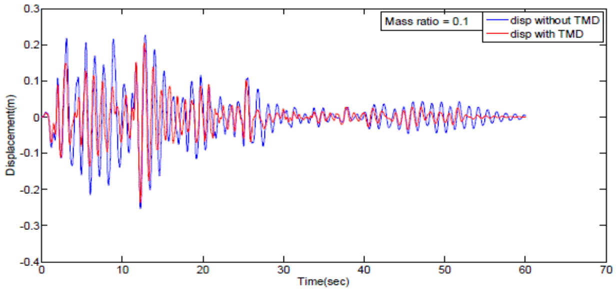

**Figure 13:** Mass ratio 0.1 (Displacement of the 3D frame with and without single TMD at 10th floor under EW component of 1940 El-Centro earthquake.)

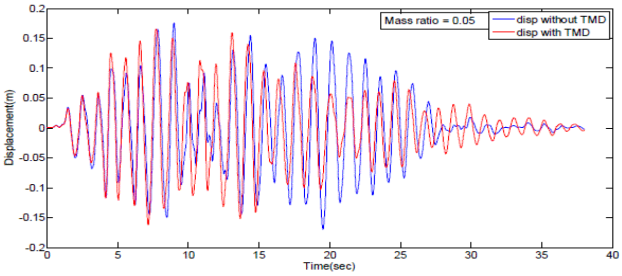

**Figure 14:** Mass ratio 0.05 (Displacement of the 3D frame with and without single TMD at 10th floor under Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil.)

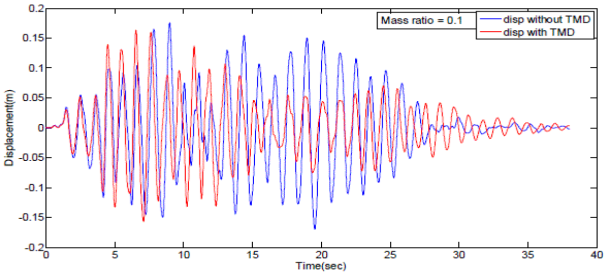

**Figure 15:** Mass ratio 0.1 (Displacement of the 3D frame with and without single TMD at 10th floor under Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil)

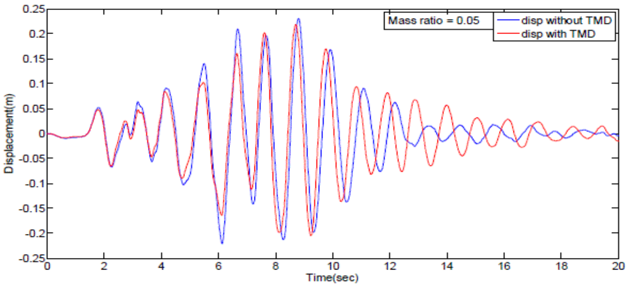

**Figure 16:** Mass ratio 0.05 (Displacement of the 3D frame with and without single TMD at 10th floor under Sakaria earthquake)

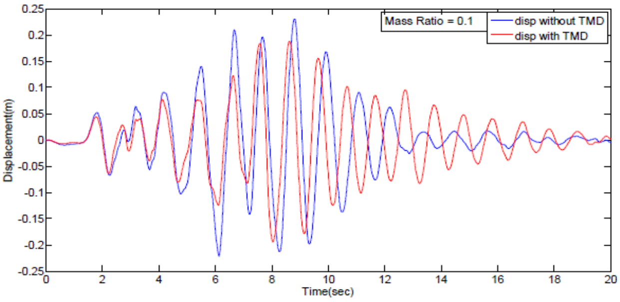

**Figure 17:** Mass ratio 0.1 (Displacement of the 3D frame with and without single TMD at 10th floor under Sakaria earthquake)

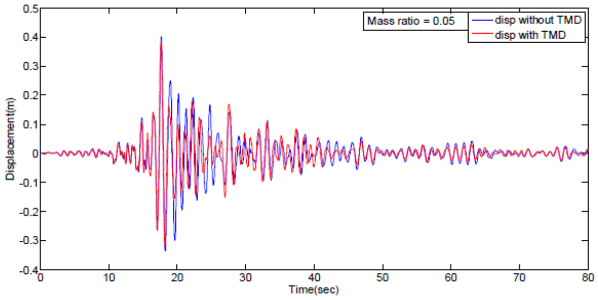

**Figure 18:** Mass ratio 0.05 (Displacement of the 3D frame with and without single TMD at 10th floor under The Landers earthquake)

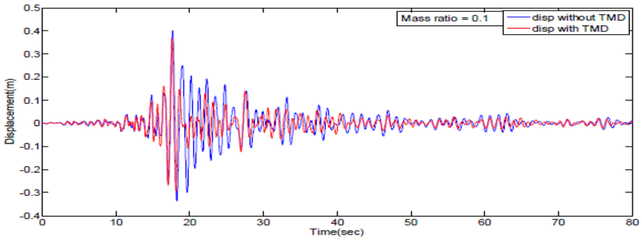

**Figure 19:** Mass ratio 0.1 (Displacement of the 3D frame with and without single TMD at 10th floor under The Landers earthquake)

Table 1. Comparative study on the Maximum displacement (m) at the top floor of the 3D frame with and without single TMD (with variation of mass ratio)

## D. LINEAR TIME HISTORY ANALYSIS OF 3D FRAME WITH AND WITHOUT DOUBLE TMD

The effectiveness of double tuned mass damper for vibration control is studied by linear time history analysis of the 3D frame under a sinusoidal load and the five numbers past earthquake data. The damping ratio of the 3D frame is taken as 0.05 for every mode. First frequency of the frame without TMD is tuned to the frequency of the first and second damper respectively. The response is calculated in term of displacement at the 10th floor.

### 1. Effect of uniform mass ratio of both TMD on the response of the 3D frame

Here response of the 3D frame (in term of displacement) is calculated with equal mass ratio of 0.05 for each TMD under sinusoidal acceleration and random earthquake ground acceleration**.** The damping ratio of the damper is taken as 0.05.

(a) **Sinusoidal acceleration**

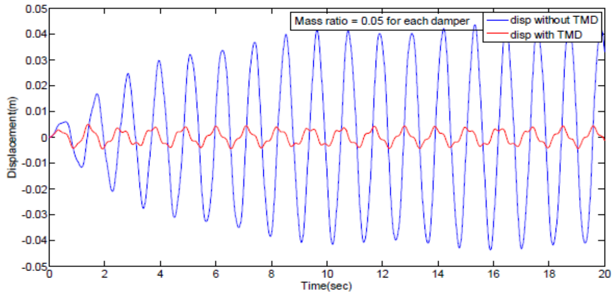

Figure 20: Displacement of the 2D frame with and without double TMD at 10th floor under sinusoidal ground acceleration with uniform mass ratio of 0.05

(b) **Random earthquake ground acceleration**

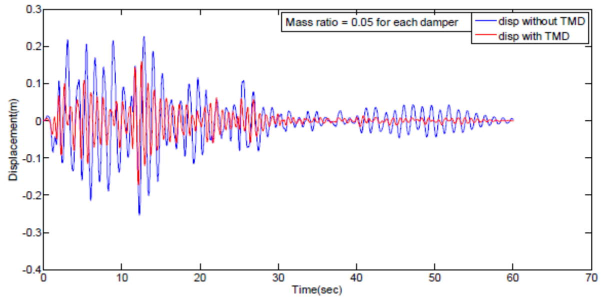

Figure 21: Displacement of the 3D frame without and with double TMD at 10th floor under EW component of 1940 El-Centro earthquake with uniform mass ratio of 0.05

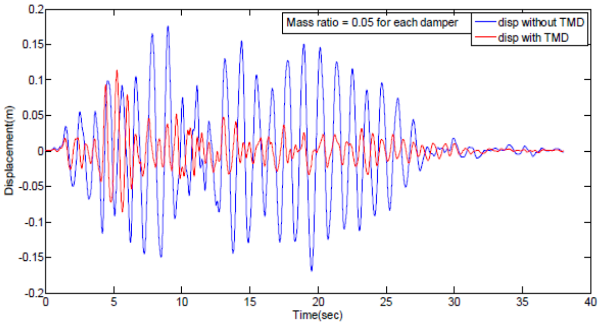

Figure 22: Displacement of the 3D frame with and without double TMD at 10th floor under Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil with uniform mass ratio of 0.05

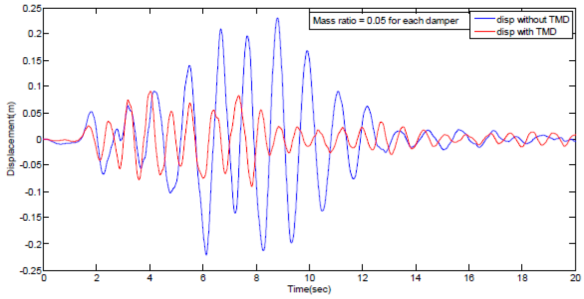

Figure 23: Displacement of the 3D frame with and without double TMD at 10th floor under Sakaria earthquake with uniform mass ratio of 0.05

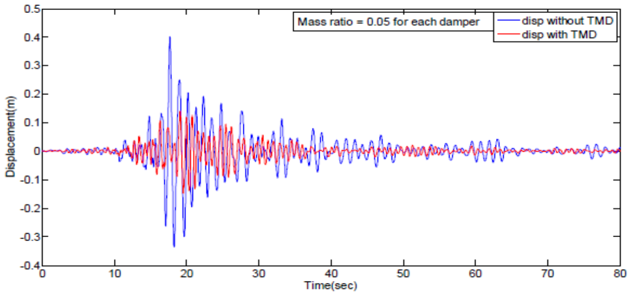

Figure 24: Displacement of the 3D frame with and without double TMD at 10th floor under The Landers earthquake 1992 with uniform mass ratio of 0.05

Table 2. Comparative study on the maximum displacement (m) of the 3D frame without and with single or double TMD (uniform mass ratio of 0.05 for each damper)

| **Type of loading** | **Without TMD (A)** | **With TMD of mass ratio 0.05 (B)** | **With TMD of mass ratio 0.1 (C)** | **(A-B)** | **(A-B) *100/A [%]** | **(A-C)** | **(A-C) *100/A [%]** | **(B-C)** | **(B-C) *100/B [%]** |
|---|---|---|---|---|---|---|---|---|---|
| Sinusoidal acceleration | 0.0426 | 0.0293 | 0.0202 | 0.0133 | 31.22 | 0.0224 | 52.58 | 0.0091 | 31.06 |
| El-Centro earthquake accelerogram 1940 | 0.2542 | 0.2540 | 0.2358 | 0.0002 | 0.08 | 0.0184 | 7.23 | 0.0182 | 7.16 |
| Spectra of IS 1893 (part 1):2002 for 5% damping at rocky soil | 0.1757 | 0.1658 | 0.1633 | 0.0099 | 5.63 | 0.0124 | 7.05 | 0.0025 | 1.50 |
| Sakaria earthquake accelerogram | 0.2305 | 0.2158 | 0.1876 | 0.0147 | 6.38 | 0.0429 | 18.61 | 0.0282 | 13.06 |
| The landers earthquake accelerogram | 0.4011 | 0.3877 | 0.3676 | 0.0134 | 3.34 | 0.0335 | 8.35 | 0.0201 | 5.18 |
| Mexico earthquake accelerogram | 0.3599 | 0.2763 | 0.2121 | 0.0836 | 23.22 | 0.1478 | 41.06 | 0.0642 | 23.24 |

Effectiveness of double TMD with uniform mass ratio to structural mass ratio is considered here. From table 1 it is found that double TMD with uniform mass ratio are much more effective in vibration control than a single TMD of same mass. Maximum response reduction of the 3D frame also increases with increase in TMD mass to structural mass ratio. Here under almost all earthquake significant response reduction takes place but not at that much rate as in case of sinusoidal load. The maximum response reduction is 89.55 % for sinusoidal ground acceleration and 65.25% for the Landers earthquake acceleration.

## 2. Effect of damping ratio variation of both TMD on response of the 3D frame for uniform mass ratio

The effect of variation of damping ratio of both TMD is studied through the response of the 3D frame (in term of displacement). Equal mass ratio of 0.05 for each TMD is considered under sinusoidal acceleration and random earthquake ground acceleration.

### (a) **Sinusoidal Acceleration**

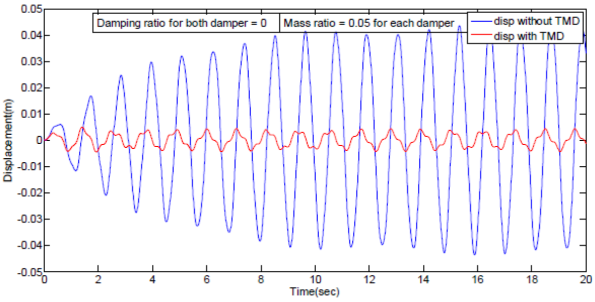

**Figure 25:** Displacement of the 3D frame without and with double TMD at 10th floor under sinusoidal ground acceleration with uniform mass ratio of 0.05. For both TMD damping ratio 0

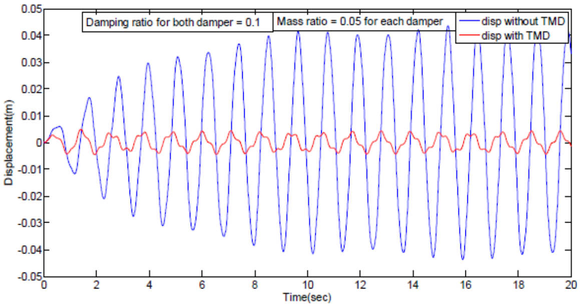

**Figure 26:** Displacement of the 3D frame without and with double TMD at 10th floor under sinusoidal ground acceleration with uniform mass ratio of 0.05. For both TMD damping ratio 0.1

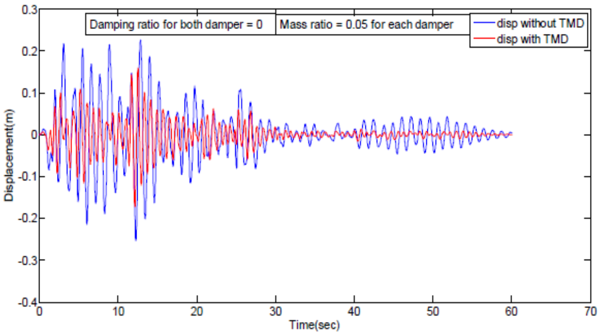

**Figure 27:** Displacement of the 3D frame with and without double TMD at 10th floor under EW component of 1940 El-Centro earthquake with uniform mass ratio of 0.05. For both TMD damping ratio 0

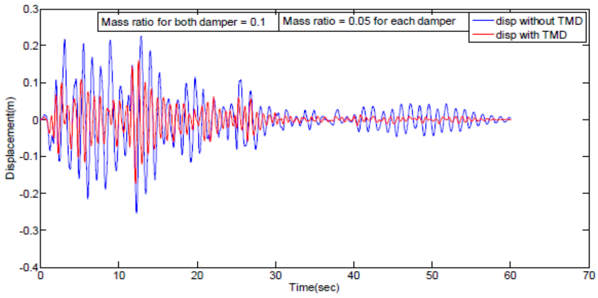

**Figure 28:** Displacement of the 3D frame with and without double TMD at 10th floor under EW component of 1940 El-Centro earthquake with uniform mass ratio of 0.05. For both TMD damping ratio 0.1

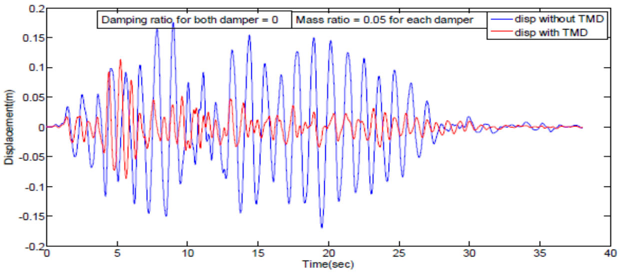

**Figure 30:** Displacement of the 3D frame with and without double TMD at 10th floor under Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil with uniform mass ratio of 0.05. For both TMD damping ratio 0

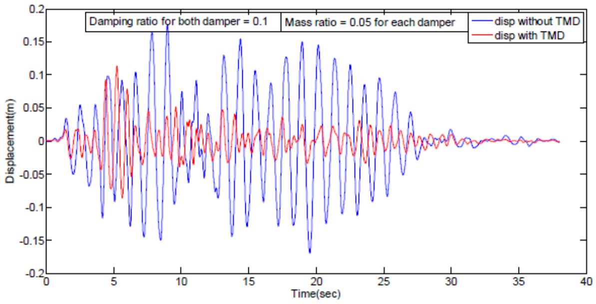

**Figure 31:** Displacement of the 3D frame with and without double TMD at 10th floor under Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil with uniform mass ratio of 0.05. For both TMD damping ratio 0.1

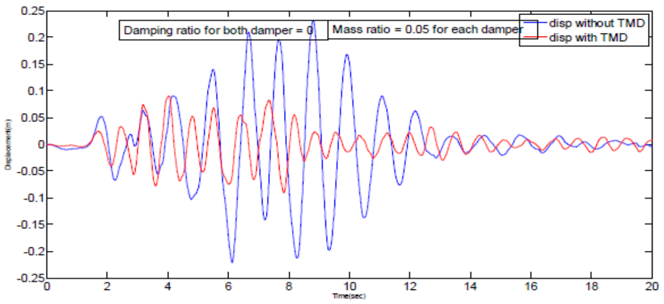

**Figure 32:** Displacement of the 3D frame with and without double TMD at 10th floor under Sakaria earthquake with uniform mass ratio of 0.05. For both TMD damping ratio 0

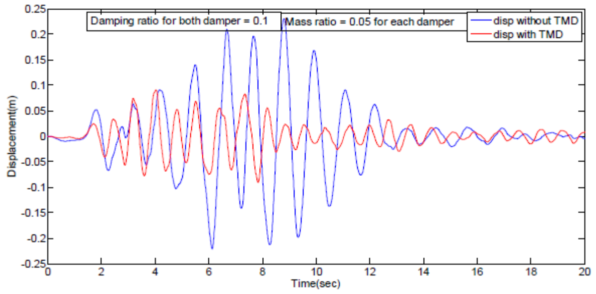

**Figure 33:** Displacement of the 3D frame with and without double TMD at 10th floor under Sakaria earthquake with uniform mass ratio of 0.05. For both TMD damping ratio 0.1

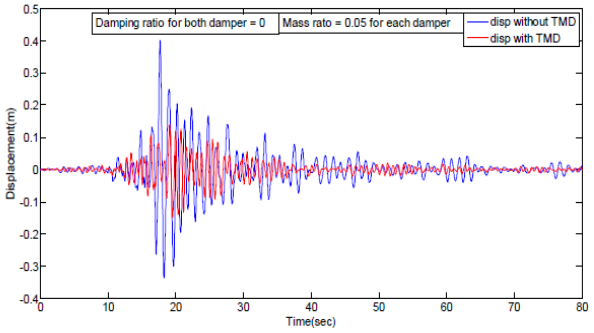

**Figure 34:** Displacement of the 3D frame with and without double TMD at 10th floor under The Landers earthquake 1992 with uniform mass ratio of 0.05. For both TMD damping ratio 0

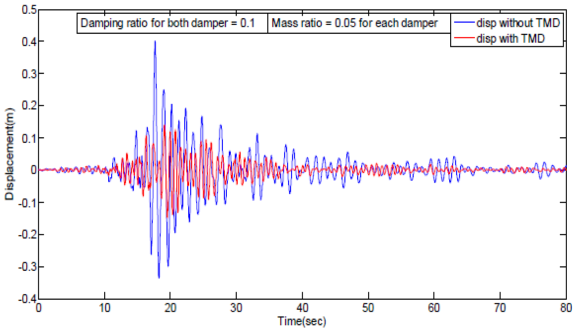

**Figure 35:** Displacement of the 3D frame with and without double TMD at 10th floor under The Landers earthquake 1992 with uniform mass ratio of 0.05. For both TMD damping ratio 0.1

From the above figures it is found that the response of the 3D frame does not change with change in damping ratio of the damper and even maximum values of response remain constant. Hence damping ratio of the damper has no or zero effect on the response of the 3D frame under sinusoidal as well as random ground acceleration.

## IV. CONCLUSION

Present study focused on the ability of Multiple TMD to reduce earthquake induced structural vibration. Linear time history analysis of the frame has been done without TMD, with single TMD and with double TMD. Two values of mass ratio of single TMD i.e., 0.05 & 0.1 is considered. Similarly double TMD is considered for mass ratio 0.05 each. From study it can be concluded that:

1) Response of the frame building reduces with the increase in mass ratio of the single TMD.
2) TMDs are much more effective to reduce structural vibration when subjected to sinusoidal ground acceleration.
3) Double TMD with uniform distribution of mass ratio is more effective than single TMD of same mass ratio.
4) The frame has same response with single and double TMD if double TMD with uniform distribution of mass ratio is tuned to same structural frequency.
5) The response of the frame building has no effect on the variation of damping ratio of the damper.

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