Effects of Multiple Tune Mass Dampers on Unsymmetric Structures

HELLO!

I am Deepak Choudhary

Roll no. -17CE31001

Fifth-year Undergraduate student

Civil Engineering Department

IIT Kharagpur

Effects of Multiple Tune Mass Damper (Different Combination) on Unsymmertic Steel Frame Structure when it is subjected to different type of loading (Cosine and Yermo Function)

1 Introduction

Introduction

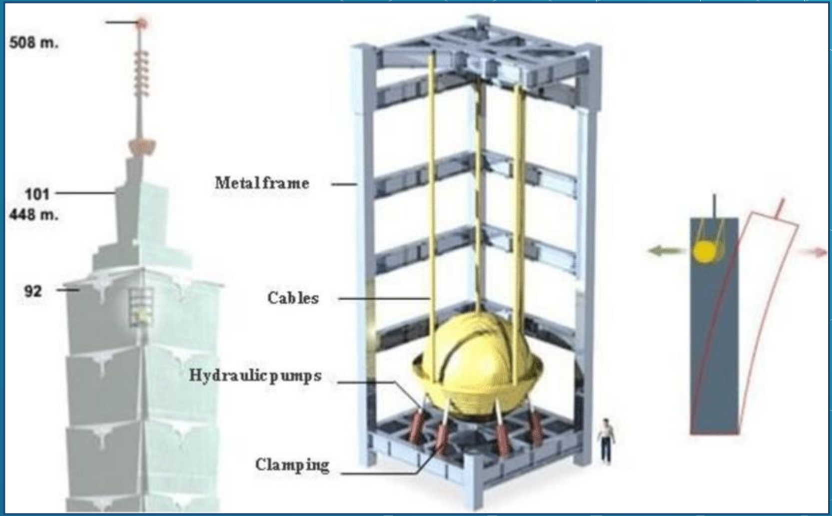
A Tuned Mass Damper (TMD), also known as a harmonic absorber or seismic damper, is a structure-mounted device that consists of a mass positioned on one or more damped springs to minimise mechanical vibrations

TMDs can help you avoid structural collapse. They're commonly seen in transmission systems, vehicles, and structures.

Its oscillation frequency is tuned to be similar to the resonant frequency of the object it is mounted to, and reduces the object's maximum amplitude while weighing very much less than it

Introduction

- TMDs are used in many high-rise buildings around the world and some of them have resisted recent earthquakes. Taipei 101’s damper was built at a cost of US $4 million, its weight is 730 tons, it is the world’s largest tuned mass damper, and perhaps the only one visible to the public.



2

Literature Review

Primary Concept

Frahm, 1909 introduced the primary concept of TMD for the first time, His proposed absorber is a mass-spring system attached to the main system at a frequency equal to that of the main system and is effective only when its natural frequency is set equal to the excitation frequency. Therefore, the main system keeps completely stationary.

Den Hartog and *Ormondroyd, **1928*** attached damping elements to Frahm's model in order to increase suppression frequency band and thereby improve its efficiency. Extension of the theory to damped system has been studied by numerous researchers till then.

Different Type of Damper

Passive energy dissipation systems utilise a number of materials and devices for enhancing damping, stiffness and strength, and can be used both for natural hazard mitigation and for rehabilitation of aging or damaged structures.

The active control method requires an external source to activate the control system that generates a control signal to modify the structural response

Semi-active control systems are a class of active control systems for which the external energy requirements are less than typical active control systems.

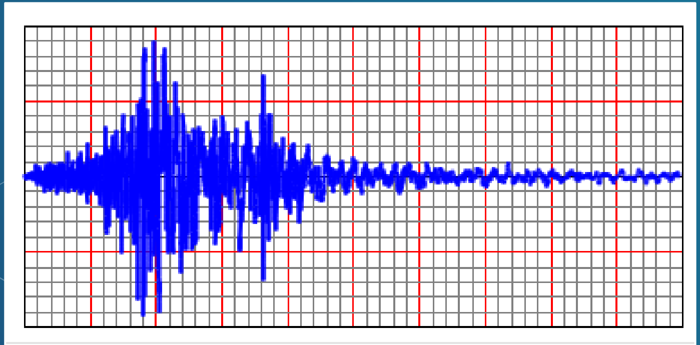
Multiple Tune Mass Damper

*Clark, **1988*** [6] first introduced the concept of the multiple Tuned mass system. Single TMD can effectively reduce the first modal response of the structure when tuned to the fundamental frequency of the system but the other higher modes may not get suppressed substantially.

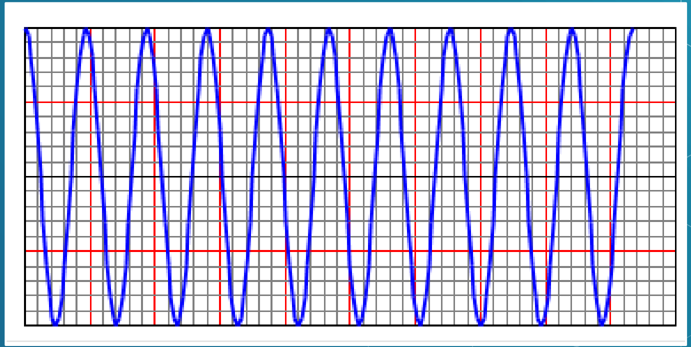
In order to attain reduction in response of different modes, multiple TMD's much be used tuned to respective modal frequencies of the system.

Time History Function

We will use Cosine wave and Yermo wave. Data from natural Earthquake in Yermo, California 1992, which are widely used in seismic design and experimental research, is used in this paper.



Yermo Function

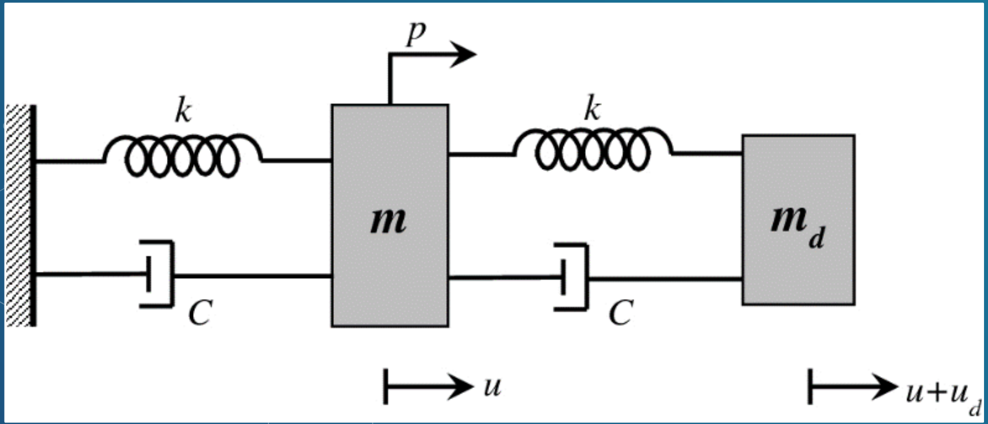


Cosine Function

3 Mathematical Formulation

Mathematical Formulation

A theory for the TMD was presented later in the paper by Ormondroyd & Den Hartog, followed by a detailed discussion of optimal tuning and damping parameters in Den Hartog's book. The concept of the tuned mass damper is illustrated using the two-mass system shown in Figure



$$\omega^2 = \frac{k}{m}$$

$$c = 2\xi\omega m$$

$$\omega_d^2 = \frac{k_d}{m_d}$$

$$c_d = 2\xi_d\omega_d m_d$$

Mathematical Formulation

The governing equations of motion are given by,

- Primary mass - $$(1+\bar{m})\ddot{u} + 2\xi\omega\dot{u} + \omega^2 u = \frac{p}{m} - \bar{m}\ddot{u}_d$$
- Tuned mass - $$\ddot{u}_d + 2\xi_d\omega_d\dot{u}_d + \omega_d^2 u_d = -\ddot{u}$$

Considering a periodic excitation, the response is given by equation where $\hat{u}$ and δ denote the displacement amplitude and phase shift respectively.

- $$\hat{u} = \frac{\hat{p}}{k\bar{m}}\sqrt{\frac{1}{1+\left(\frac{2\xi}{m}+\frac{1}{2\xi_d}\right)^2}}$$
- $$\hat{u}_d = \frac{1}{2\xi_d}\hat{u}$$

Mathematical Formulation

To compare these two cases, we can express the above equation in terms of an equivalent damping ratio

- $\hat{u} = \frac{\hat{p}}{k}\left(\frac{1}{2\xi_e}\right)$
- $\xi_e = \frac{\bar{m}}{2}\sqrt{1 + \left(\frac{2\xi}{\bar{m}} + \frac{1}{2\xi_d}\right)^2}$

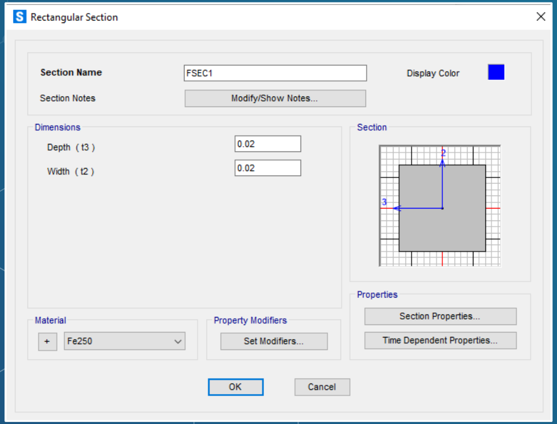
Preliminary design of a TMD for a SDOF system - Suppose ξ = 0 and we want to add a tuned mass damper such that the equivalent damping ratio is 10%.

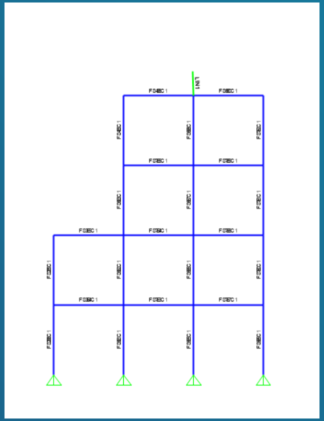
- $\frac{\bar{m}}{2}\sqrt{1 + \left(\frac{1}{2\xi_d}\right)^2} = 0.1$
- $\hat{u}_d = \frac{1}{2\xi_d}\hat{u}$
- $\bar{m} \approx 2\xi_e\left(\frac{1}{\hat{u}_d/\hat{u}}\right)$

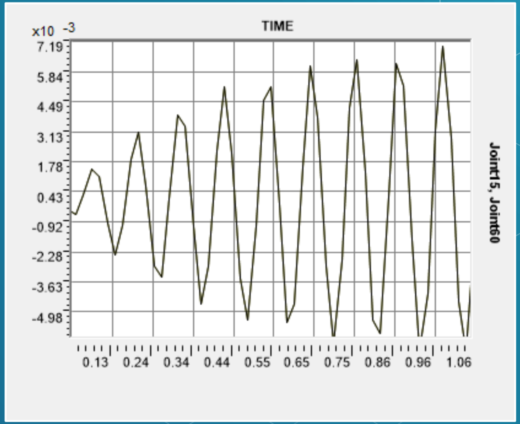
4 Methodology

Methodology

- In this project 2D unsymmetric portal frames of 4 storey and total height 2m are considered for the numerical study of the structures installed with Tuned mass damper system

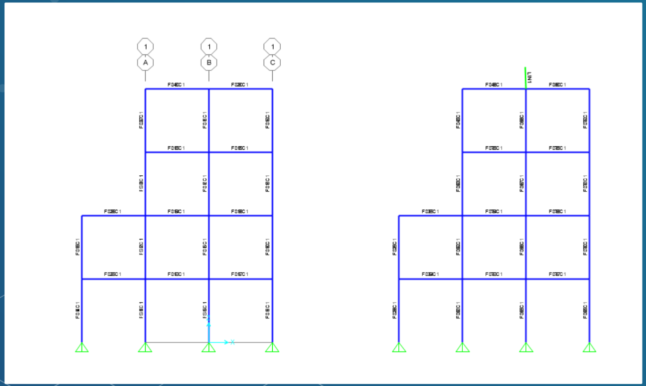


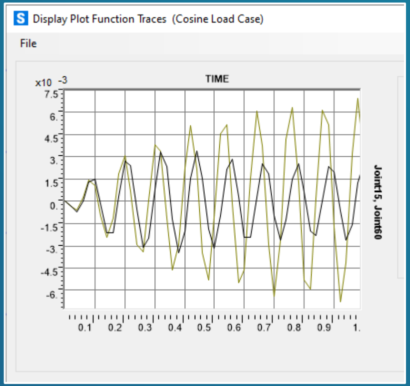


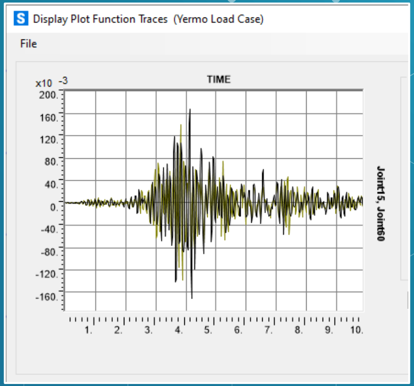


Methodology

- A TMD tuned to this frequency and with a mass ratio of 0.02 was introduced to the system. Then again both structures are subjected to same cosine load case.



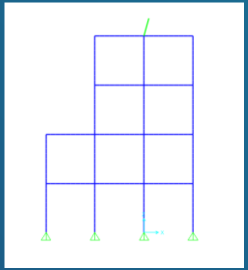


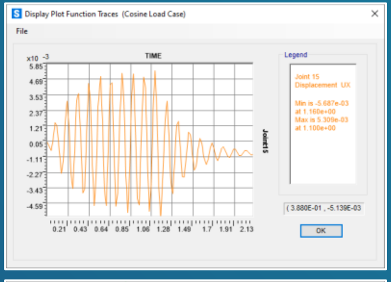


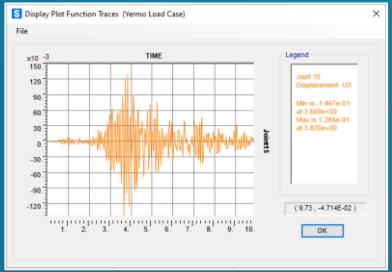
4 Numerical Investigation

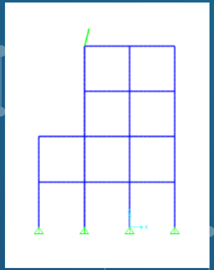
Single TMD on Same Floor but different position

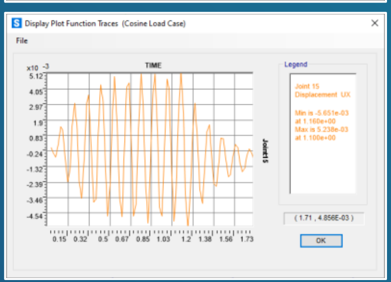
Comparing single and same TMD positioned at different position at 4th floor, the topmost floor. For Yermo Load function maximum amplitude decrease when we move second column to the third column. Same changes can be seen for cosine function.

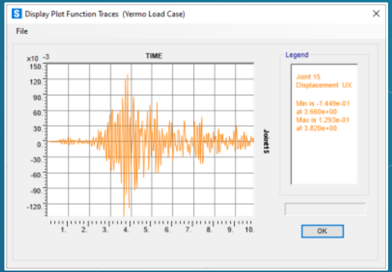






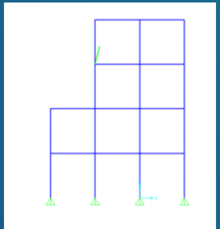


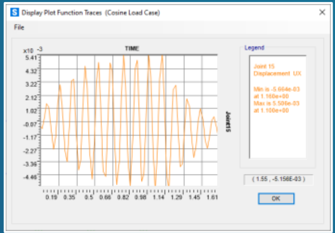


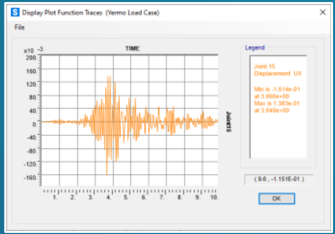


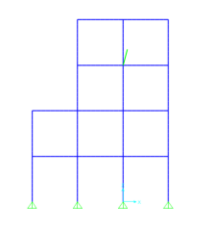
Single TMD on Same Floor but different position

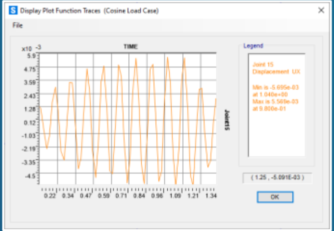
Comparing single and same TMD positioned at different position at 3rd floor. For Yermo Load function maximum amplitude decrease when we move second column to the third column. Same changes can be seen for cosine function. Deflection in case of third floor is greater than Fourth Floor condition.

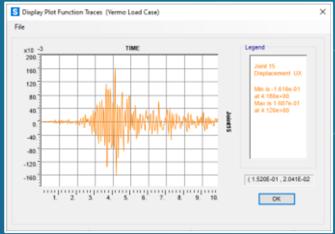






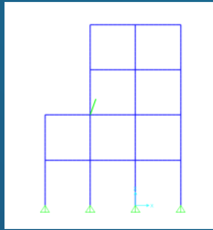


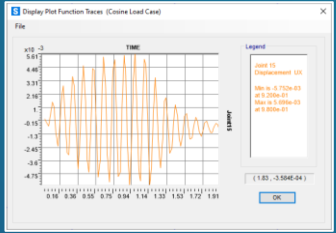


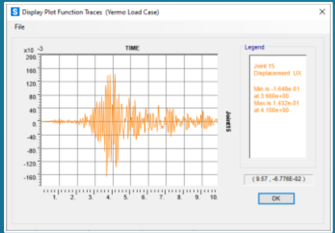


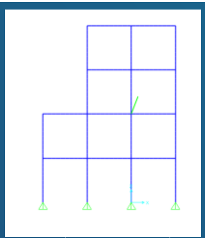
Single TMD on Same Floor but different position

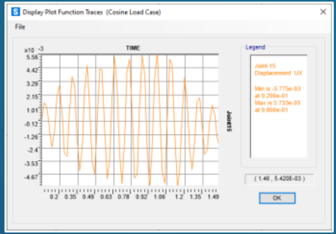
- Comparing single and same TMD positioned at different position at 2nd floor. For Yermo Load function maximum amplitude decrease when we move second column to the third column. Same changes can be seen for cosine function. Deflection in case of Second floor is greater than Fourth and Third Floor condition.

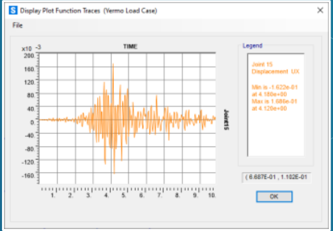






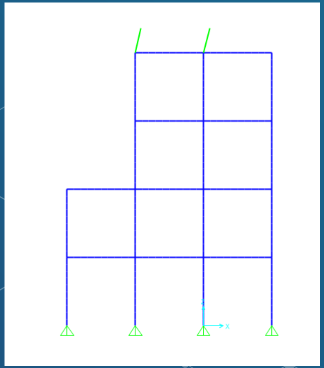


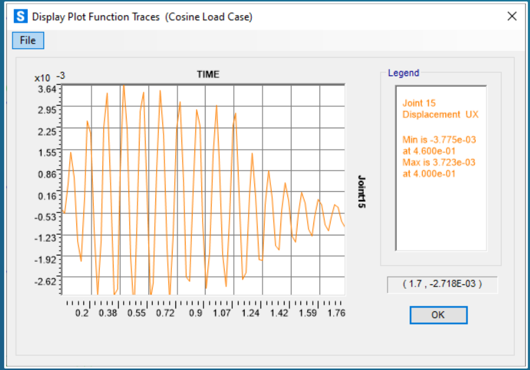


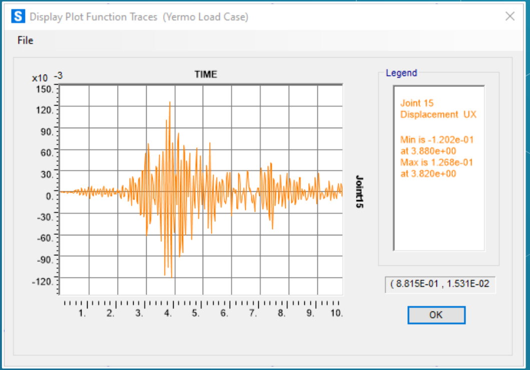


Effect of Multiple TMD

Comparing multiple TMD at 4th floor, the topmost floor. The amplitude in case of Multiple TMD on Fourth Floor is small as compared to results that we observe in section 4.2 for single MTD. This observation is same for both load cases.

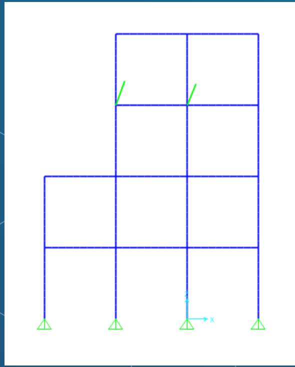


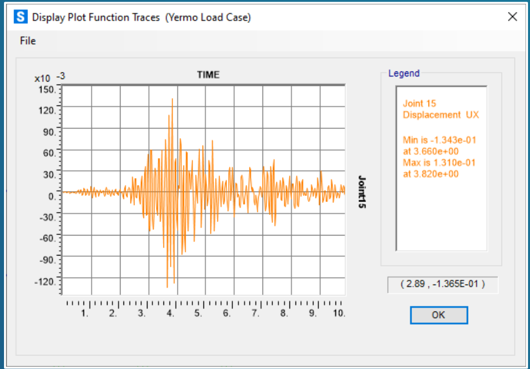


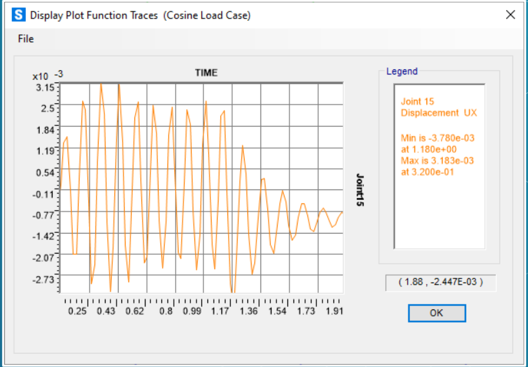


Effect of Multiple TMD

Comparing multiple TMD at 3rd floor. The amplitude in case of Multiple TMD on Third Floor is slightly greater as compared to results that we observed in case of multiple TMD on Fourth Floor. This observation is same for both load cases.

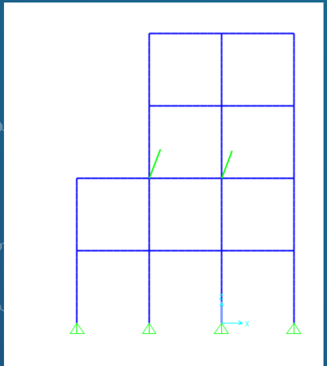


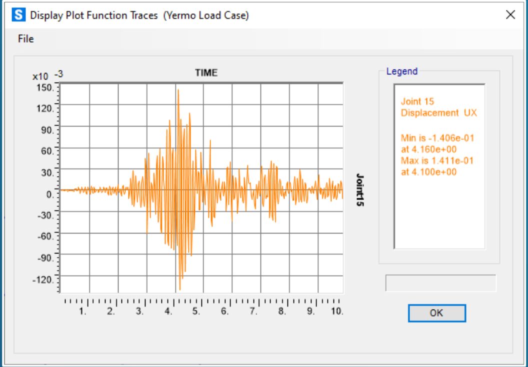


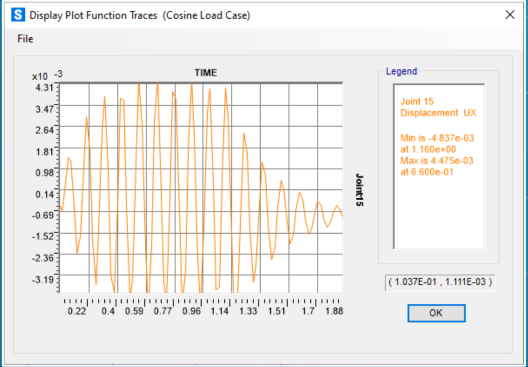


Effect of Multiple TMD

Comparing multiple TMD at 2nd floor. The amplitude in case of Multiple TMD on Third Floor is greater as compared to results that we observed in above cases. This observation is same for both load cases.

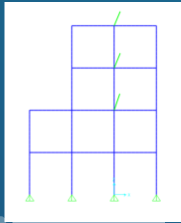


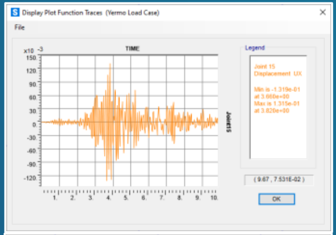


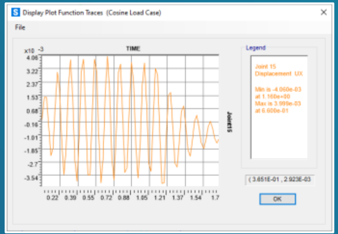


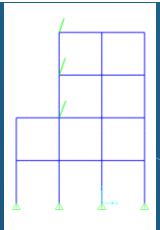
Effect of Multiple TMD

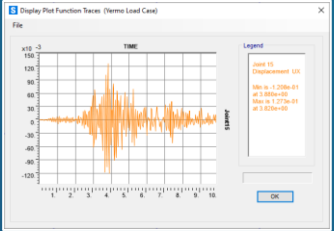
Comparing multiple TMD on several floor. Multiple TMD is placed on each floor (2nd, 3rd and 4th floor). The amplitude in case of this Multiple TMD combination is slightly closer to value we get for Multiple TMD only on 4th floor. But in this case one extra TMD is used. This observation is same for both load cases.

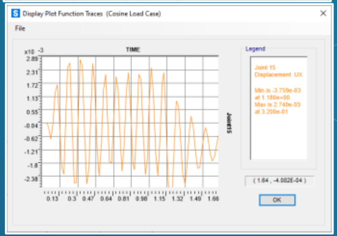












Observations

When comparing effect of Single TMD on Same Floor at different position, we get:

- When we look at a single TMD at any point, we can see that the maximum amplitude generated by Yermo load and the cosine load both decrease when TMD is moved to higher levels. As we go TMD from the 4th to the 3rd floor, and then from the 3rd to the 4th floor, the amplitude increases.
- For Unsymmetric Structure, we get better results when TMD is in the second column (the weak column with fewer supports). TMD amplitude on the second column is always less than TMD amplitude on the third column.
- When structures with the identical TMD cases are treated to both Load cases (Yermo and Cosine), the amplitude decreases more when the cosine load is applied.

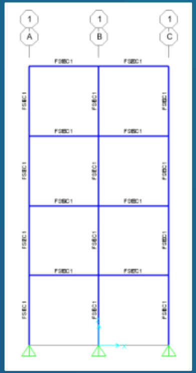
Observations

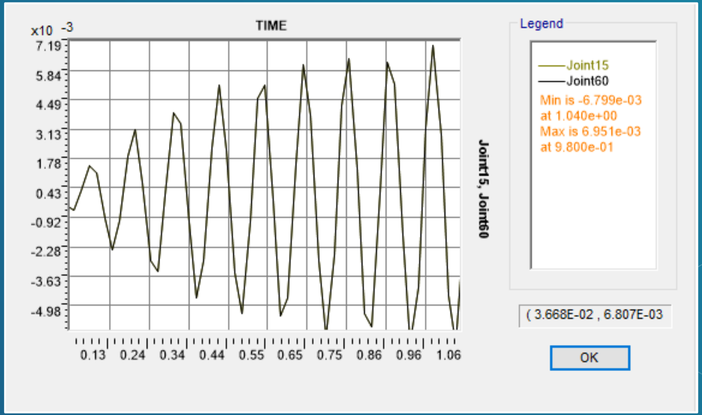
When comparing effect of Multiple TMD on Different Floor, we get:

- When we compare result of Multiple TMD to single TMD, we get better result when Multiple TMD is used. It works for both load cases.
- When we compare Multiple TMD on different floor, Amplitude decreases when we move TMDs to lower level.
- When comparing result of Using Multiple TMD on several Floor. Multiple TMD is placed on each floor (2nd, 3rd and 4th floor) we get better result When Placed at Second Column (the weak column with fewer supports).
- We get close result in cases when Two TMD placed at 4th Floor and Single TMD on each Floor. But in later condition one extra TMD is used.

Effect of Multiple TMD on Symmetric Structure

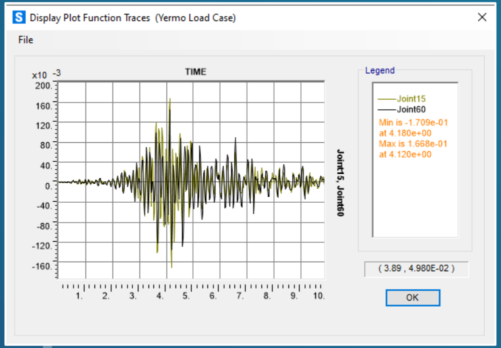
In this part 2D Symmetric Portal frames of 4 storey and total height 2m are considered for the numerical study of the structures installed with Tuned mass damper system.

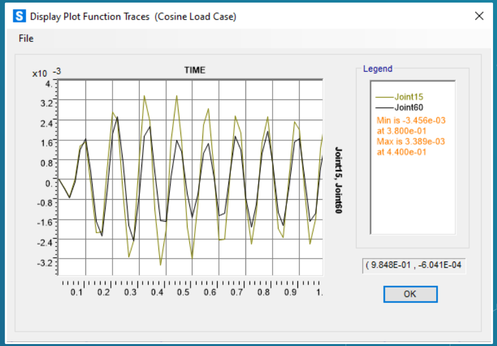




Effect of Multiple TMD on Symmetric Structure

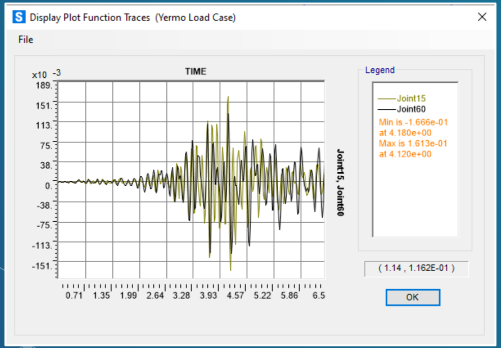
Multiple TMD Located on 4th floor and 3rd floor. Red Line shows case for single TMD on 4th floor. Black Line shows Multiple TMD (TMD on each 4t floor and 3rd floor). This time we are getting even better damping than single TMD on Top floor.

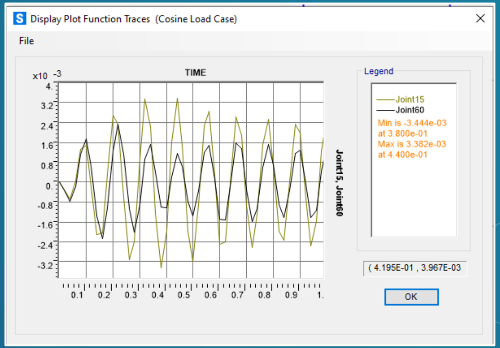




Effect of Multiple TMD on Symmetric Structure

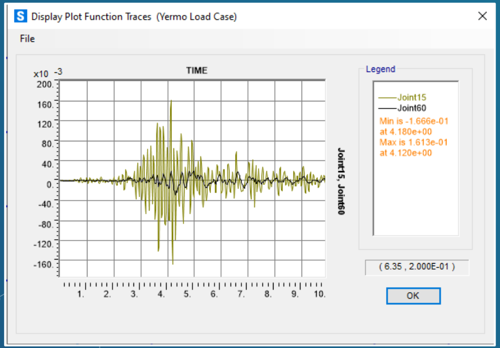
- Multiple TMD Located on 4^{th} ,3^{rd} and 2^{nd} floor. Red Line shows case for single TMD on 4^{th} floor. Black Line shows Multiple TMD (TMD on each 4^{th}, 3^{rd} and 2^{nd} floor). This time we are getting even better damping than previous combination. Even for Yermo Load case now we can significant difference in amplitude.

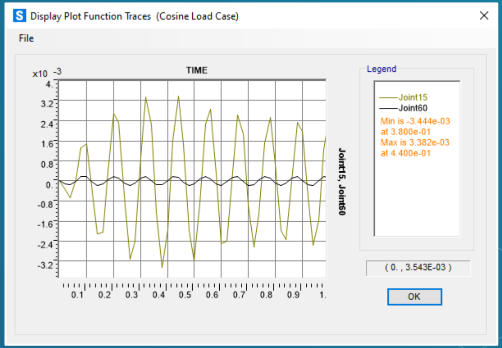




Effect of Multiple TMD on Symmetric Structure

- Multiple TMD Located on each floor. Red Line shows case for single TMD on 4th floor. Black Line shows Multiple TMD (TMD on each floor). This time we are getting even better damping than previous combination. Even for Yermo Load case now we can significant difference in amplitude.





Effect of Multiple TMD on Symmetric Structure

- In case of Symmetrical model for Yermo Model Case, Single TMD was not very effective. Vibration reduced a little (which is not a negligible quantity). Whereas For Multiple TMD cases one can get better result.
- For TMD on each Floor we get the best result in vibration reduction, but it is not feasible as installation of TMD takes large volume, is heavy and costly

4

Conclusion and Future Work

Conclusion

The TMD and its efficiency in managing the structure's reaction are the topic of this thesis. We simulated effect of Tune Mass Damper on a Steel structure using SAP2000 Software. We compared result between Different load cases and combination of different TMD (Single TMD and Multiple TMD)

Following conclusions can be made from this study –

- For Single TMD cases, we can clearly state that TMD when situated at highest Floor (4th floor) we get best result as compare to TMD situated at other three floors. Therefore, we can state that TMD when placed on high floor work better in comparison of Lower floors.

Conclusion

- For Cosine Load Case, we used Frequency for first mode, for this load case even single TMD works perfectly in order to reduce vibration.
- For Yermo Model Case, Single TMD was not very effective. Vibration reduced a little (which is not a negligible quantity). Whereas For Multiple TMD cases one can get better result.
- For TMD on each Floor we get the best result in vibration reduction, but it is not feasible as installation of TMD takes large volume, is heavy and costly.
- For Structures That Are Not Symmetrical TMD should be installed on the column that experiences the most deflection during load application. This results in a better amplitude decrease.

Further Scope of work

Computer simulation alone is not a solid proof for any theory.

- We need to Simulate these result in laboratory with similar model and TMD. After comparison we can get even better result.
- Parametric and optimization study need to be done to find out the optimal locations for placing the MTMD on the asymmetric Frames.
- The TMD studied in this paper is modelled as an un-damped system; however, in fact, TMD performance may be enhanced by dampening the TMDs properly. This is something that has to be looked at more, both analytically and empirically.

Reference

- Frahm H, *Device for damping of bodies*. U.S. Patent No: 989,958; 1911.
- Den Hartog, J. P., & Ormondroyd, J. (1928). Theory of the dynamic vibration absorber. *ASME J. Appl. Mech*, *50*(7), 11-22.
- Blekherman A.N (1996) —Mitigation of response of high-rise structural systems by means of optimal tuned mass damper || *Eleventh world conference on Earthquake Engineering paper no-89*
- Davorin Hrovat, Pinhas Barak, and Michael Rabins (1983) - Semi-Active versus Passive or Active Tuned Mass Dampers for Structural Control || *Journal of Engineering Mechanics. Volume 109, Issue 3*
- Shamali Bijan, Al-Dawod Mohammed (2003) —Performance of a five-storey benchmark model using an active tuned mass damper and a fuzzy controller || *Engineering Structures 25 pp 1597–1610*
- Clark J. Allen (1988) - Multiple passive TMDs for reducing earthquake induced building motion || *Proceedings of ninth world conference on Earthquake Engineering Tokyo Kyoto Japan,Vol.5*
- Farghaly, Ahmed Abdelraheem, and Mahmoud Salem Ahmed. "Optimum design of TMD system for tall buildings." *International Scholarly Research Notices* 2012 (2012).
- Li, Jiuyang, Fangqi Li, and Zhiru Cai. "Seismic analysis of multi-story frame office building based on SAP2000." *IOP Conference Series: Earth and Environmental Science*. Vol. 768. No. 1. IOP Publishing, 2021.

THANKS!

- Deepak Choudhary
- deepakdc1910@gmail.com