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Dynamic Response Reduction of Reinforced Concrete Structure using Tuned Mass Damper and Tuned Liquid Damper

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Abstract

Damping devices are used to reduce the dynamic response of a structure by energy dissipation. Common types of damping devices are fluid viscous dampers, tuned mass dampers, and tuned liquid dampers. This project aims to study the effectiveness of TMD and TLD in controlling the response of the structure when it is subjected to acceleration records of different earthquakes. A 20-storey reinforced concrete bare frame structure has been subjected to two earthquake acceleration records with and without dampers in SAP 2000. The dampers are modelled using link elements. The structure is attached with TMD and TLD having a mass of 0.5%, 2%, 4%, 6%, 8% and 10% of the modal mass. The analysis procedure used is nonlinear modal time history analysis (FNA). The variation in base shear and top storey displacement has been obtained and plotted.

Keywords: Seismic response reduction of structures, Tuned mass damper, Tuned liquid damper, Seismic performance.

1. Introduction

Damping devices are used to reduce the dynamic response of a structure by energy dissipation. Common types of damping devices are fluid viscous dampers, tuned mass dampers, and tuned liquid dampers. This project aims to study the effectiveness of TMD and TLD in controlling the response of the structure when it is subjected to acceleration records of different earthquakes. A 20-storey reinforced concrete bare frame structure has been subjected to four earthquake acceleration records with and without dampers in SAP 2000. The dampers are modelled using link elements. The structure is attached with TMD and TLD having a mass of 0.5%, 2%, 4%, 6%, 8% and 10% of the modal mass. The analysis procedure used is nonlinear modal time history analysis (FNA). The variation in base shear, top storey displacement, and maximum acceleration has been obtained and plotted.

Since the major portion of the loss of life is due to the collapse of the buildings during the earthquake, there occurred a huge demand for the development of technologies and methods for the mitigation of damages to structures during earthquakes. After various studies by different researchers, one major factor that played a crucial role in the collapse of many structures was found out as lack of ductility. The overall ductility of the structure will help in the energy dissipation when the structure gets damaged without collapse. Apart from providing ductility concepts, there are many different ways we can reduce the seismic demand on the structures. Some of the most popular and widely adopted methods are by providing dampers or using base isolators. There are different types of dampers which will be discussed subsequently.

The concepts of Tuned mass dampers and tuned liquid dampers are quite intriguing. These dampers are passive energy dissipation devices and use their inertia force to counteract the motion of the primary structure. These devices are tuned to some particular structural frequencies which are needed to be controlled. For the design of a Tuned mass damper, the optimum parameters used for the design are taken from the book of Jerome Connor on Structural motion engineering. These parameters had been extended from Den Hartog's book on mechanical vibrations. The design of the Tuned liquid damper is done using the curves obtained from IS 1893 part 2. One of the main advantages of using TMDs and TLDs are, that they can be retrofitted easily in an existing building compared to another popular method like base isolation, which is also having higher maintenance requirement. Most of the older buildings and monuments do not have much inherent ductility, so these methods can be used to increase their seismic performance.

Several methods can be used for the dynamic analysis of structures. The common methods used are the response spectrum method, pushover analysis, linear time history analysis, and nonlinear time history analysis. Out of this, time history analysis has been used in this project.

Thakar V.M and Pachpor P.D (2012) studied the effect of the tuned mass damper on two models. One without

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TMD and one with TMD having the same damping ratio as the primary building. A six-storey RC building was selected and three past earthquake acceleration data were applied to it using rigorous non-linear dynamic analysis also known as the direct integration technique. The model with TMD was attached with a soft storey at the top of the structure which behaved like a tuned mass damper. The optimum parameters of the soft storey were derived from the literature of Sadek F. Free vibration analysis was done on both the models and it was found that the frequency of the model with TMD was significantly lower than the model without TMD. The mass of the TMDs was of the order of 2% and 3% of the modal mass of the building. The earthquake records applied to the structure were El-Centro, Taft and Dharamshala. A displacement reduction ranging from 10% to 50% was observed for the top storey while using TMD.

Haitham Mohamed Khalaf and K. Sandeep Kumar (2016) aimed to find out the behaviour of TMD in RC Moment resisting frames of varying heights, 15 storeys, 25 storey and 35 storey buildings with 45m, 75m and 105m height respectively. The buildings were of regular and symmetrical configuration. The TMD was configured using spring elements with viscous elastic dampers attached to it and installed at the topmost storey of the building. Discussions had been carried out about the steady-state dynamic response of a single degree of freedom structure and the resonance curve also known as the dynamic amplification curve. These curves were obtained from the literature of Den Hartog which signified the importance that the damping ratio of the TMD plays in the design of the same. An in-depth explanation of the concepts of equivalent lateral force and response spectrum method along with the various response combination techniques like SRSS and CQC were provided. A significant reduction in base shear, lateral drift and inter storey drift was noticed and has been tabulated. An increase in the percentage reduction in overall response was also observed when the number of stories in the building increased. The optimal position of the TMD for maximum effectiveness is found on the top storey floor.

Balachandar M and Vinod Y (2018) have conducted a study about the suitability of TMD, a passive control device which does not require any external energy source. A brief explanation about active control devices and semi-active control devices was also provided. The basic concept of TMD i.e., out of phase action of TMD at the frequency to which the structural response was to be reduced has been emphasized. The building under consideration is a G+9 storey building and models are made with and without TMD. The TMDs are configured for 3%, 6% and 9% of the primary mass of the structure and the analysis results showed a higher percentage of response reduction for the models having higher mass ratios.

H A Admane, Y.D. Shermale and R.S. Jaiswal (2017) analyzed A G+12 storey building of rectangular configuration and made of RCC were analyzed using a nonlinear direct integration technique by applying three different earthquakes, namely, El-Centro, Northridge and Taft. The masses of the TMD considered were 2%, 3%, 4% and 5%. The TMD was designed as a soft storey at the top. Various advantages and disadvantages of the base isolation technique regarding the suitability with the increase in weight of the structure and maintenance requirement of these systems were noted. The disadvantage of an active control device which is the constant availability of power supply and therefore the cost-effectiveness in a developing country like India was reviewed. A lot of parameters were needed to be considered during the selection of dampers, like weight, capital cost, operating cost, maintenance requirement and safety. The mechanisms of energy dissipation like internal straining, rubbing, cracking and plastic deformation along with the conversion of kinetic energy to heat and devices operating by this principle were discussed. The analysis results show a reduction of 20% to 60% in top storey displacement for different mass ratios and different earthquakes considered.

Ashish A. Mohite and G.R. Patil (2015) conducted a study of symmetrical multi-storey 10,12,14,16,18 and 21 storey RC Moment resisting frame structure was carried out. The structures are designed such that there was a reduction in the size of the columns from the ground storey to the upper stories. The need for tall structures considering different factors like economic growth is discussed among which was the scarcity of land. Basic principles regarding responses due to excitation when a TMD is attached to the SDOF system were shown and corresponding equations of motion were derived. The importance of maintenance-free operation of TMD and the ability of TMDs to reduce the wind-induced vibrations and consequences of TMD systems not in operation were discussed. TMDs can also be effectively used to reduce floor vibrations. Generally, the mass ratios of TMDs were 1% to 10%, in this analysis, 5% of the primary mass was considered and acceleration data of the Bhuj earthquake was used as seismic input. The TMDs were modelled using the link element property and were attached to the columns. The seismic responses like displacement and base shear were found out and a 30% to 40% reduction in displacements was observed.

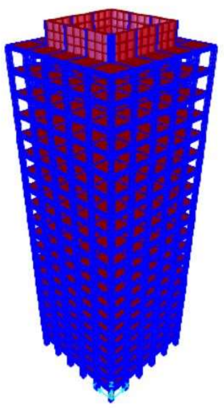
Raveesh R.M and Sahana T.S (2014) did a study on the linear dynamic response of multistoried buildings of 10, 20 and 30 stories with mass ratios of 0.25, 0.5 and 0.75 were carried out with Bhuj earthquake acceleration data as the input. The generation of earthquake waves and the causes of their creation along with other causes of wave generation like volcanic eruptions and explosive detonation were provided. The concepts of conservation of energy and how the excitation energy is absorbed by the TMDs by tuning were discussed. A brief introduction about Metallic yield dampers, Viscoelastic dampers, TMD and TLD was also made. The TMD was modelled using the elastic spring property and the increase in the period of the structure with the increase in mass ratios of the TMD were analyzed. It was found that when a mass ratio of 0.25 was used, the response reduction was maximum.

Aakash Bikram Rana, Shubhesh Bista and Prashant Sunagar (2018) subjected a G+19 storey building to a sinusoidal excitation to study its dynamic response when attached with a TLD and without a TLD. A TLD uses sloshing energy to reduce the dynamic responses of the structure. The TLD is modelled as per IS 1893 part 2 with rectangular cells. This code provides the concept of convective mass and impulsive mass and their simplified spring-mass representation and the curves provided are used for the optimal tuning of TLD cells to the desired frequency to be controlled. The optimal frequency of the TLD was found to be lower than the frequency that is being controlled. Advantages and disadvantages of TLDs were also discussed, namely the availability of water during a fire hazard but the disadvantage being the large amount of space required for installation. The reduction in the percentage of maximum displacement. Base shear and acceleration were found out.

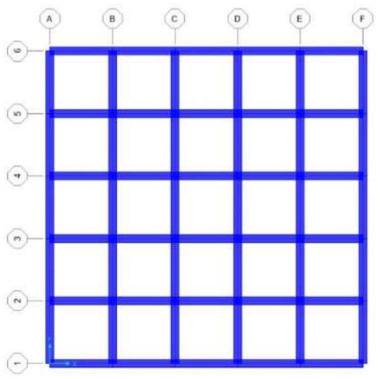
David Lee and Martin Ng (2010) studied the importance of tuned liquid dampers in tall and slender structures subjected to wind loading. A 39-storey reinforced concrete residential and commercial building called Wanchai having fundamental frequencies of 0.24 Hz and 0.26 Hz along the x and y-axis respectively, located in Hong Kong is taken for the case study. It was observed that compared to along wind, the crosswind had more damage potential because of vortex shedding. Wind tunnel testing was carried out on a scaled model (1:400) of the building along with its neighboring structures and topography. The acceleration of the top storey was monitored during the experimental study with wind loadings given as per the codal values. Acceleration was found to exceed the limiting value. The mass of the TLD is 1.5% of the total mass of the building. Two tanks were used, one in each direction to reduce response in that direction. The TLDs were found to effectively control the acceleration of the building under wind excitation.

Modelling of structure

A G+19 storey RC bare frame structure has to be modelled for the analysis. The structure has a plan dimension of 20m x 20m with 5 bays along each direction having a bay width of 4m. The structure is having a total height of 70 m. The section sizes of various members are not the same and vary with different storey levels.



(a) 3D view of structure



(b) Structural plan

Fig. 1. Structural system

Modal parameters in x direction

Natural frequency ω = $\frac{2\pi}{0.69278}$ = 9.069 rad/s

Mass of equivalent SDOF system corresponding to first mode in x direction

$$m_{1e} = 4620522.711\ kg$$

Stiffness of equivalent SDOF system corresponding to first mode in x direction

$$k_{1e} = 350244946.5\ N/m$$

Damping coefficient of equivalent SDOF system corresponding to first mode in x direction

$$c_{1e} = 4027816.885\ N\ s/m$$

Modal parameters in y direction

Natural frequency ω = $\frac{2\pi}{0.78267}$ = 8.027 rad/s

Mass of equivalent SDOF system corresponding to first mode in y direction

$$m_{2e} = 4828640.151 kg$$

Stiffness of equivalent SDOF system corresponding to first mode in y direction

$$k_{2e} = 365721087.1\ N/m$$

Damping coefficient of equivalent SDOF system corresponding to first mode in y direction

$$c_{2e} = 4022931.958\ N\ s/m$$

Total dead load of structure = 8837348.8828 kg

Design of TMD for $\bar{M}$ = 10 percent

Mass of the damper , m_d = 883734.88 kg

Y direction

$$f_{opt} = \left[\frac{\sqrt{1-0.5\times 0.18301}}{1+0.18301} + \sqrt{1-2\times 0.05^2} - 1\right] -$$

$$\left[2.375 - 1.034\sqrt{0.18301} \times 0.426 \times 0.19126\right] \times 0.05 \times$$

$$\sqrt{0.18301} \times \left[3.730 - 16.903\sqrt{0.18301} + 20.469 \times 0.18301\right] \times$$

$$0.05^2 \times \sqrt{0.18301} = 0.7632$$

$$\xi_{d\,opt} = \sqrt{\frac{3\times 0.18301}{8(1+0.18301)(1-0.5\times 0.18301)}} +$$

$$\left[0.151\times 0.05 - 0.170\times 0.05^2\right] + \left[0.163\times 0.05 + 4.980\times 0.05^2\right]$$

$$\times 0.18301 = 0.26359$$

$\omega_d = f_{opt}\omega_1 = 0.7632 \times 8.027 = 6.1266\, rad/s$

$k_d = \omega_d^2 m_d = 6.126^2 \times 883734.88 = 33171839.54$

=33171.839 KN/m

$c_d = 2\xi_{d\,opt}\omega_d m_d = 2 \times 0.25359 \times 6.1266 \times 883734.88 = 2854333.416$

= 290.9 KNs/m

X direction

$$f_{opt} = \left[\frac{\sqrt{1-0.5\times 0.19126}}{1+0.19126} + \sqrt{1-2\times 0.05^2} - 1\right] -$$

$$\left[2.375 - 1.034\sqrt{0.19126} \times 0.426 \times 0.19126\right] -$$

$$\left[3.730 - 16.903\sqrt{0.19126} + 20.496 \times 0.19216\right] \times$$

$$0.05^2 \times \sqrt{0.19126} = 0.75525$$

$$\xi_{d\,opt} = \sqrt{\frac{3\times 0.19126}{8(1+0.19126)(1-0.5\times 0.19126)}} +$$

$$\left[0.151\times 0.05 - 0.170 \times 0.05^2\right] + \left[0.163 \times 0.05 + 4.980 \times 0.05^2\right]$$

$$\times 0.19126 = 0.269083$$

$\omega_d = f_{opt}\omega_2 = 0.75525 \times 9.069 = 6.8493\, rad/s$

$k_d = \omega_d^2 m_d = 6.8493^2 \times 883734.99 = 41458575.32\, N/m$

= 41463.130 KN/m

$c_d = 2\xi_{d\,opt}\omega_d m_d = 2 \times 0.269083 \times 6.8493 \times 883734.88$

$= 3257663.01\, kgs/m = 332.075\, KNs/m$

Design of tuned liquid sloshing dampers

For mass ratio = 10 percent of the primary mass

Y direction

Table-1 Design parameters for tuned liquid damper in y direction

Natural frequency of the mode considered f '	1.2775 Hz
Mass ratio m_r	0.10
Depth ratio d_r	0.2
Zone factor Z	0.36
Importance factor I	1.5
Response reduction factor R	2
Sa/g(for soft soil)	2.1334
Ah	0.28801
Assumed wall thickness (m)	0.005

Optimal tuning frequency ratio f '= $\frac{f}{1+m_r} = \frac{1.2775}{1+0.1} = 1.16136$

As per IS 1893 part 2,

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_c}}$$

Substituting the values for k and m_c ,

$k = \frac{0.25\, m\, g}{h}$

$m_c = 0.77\, m$

Depth of water in individual cell in x direction, h= 0.05981 m

Length of individual cell in y direction, L = $\frac{depth\ of\ water\ in\ the\ cell}{dept\ \ ratio} = \frac{0.05981}{0.2}$

= 0.29905 m

maximum height of sloshing water, h_s is given by IS code,

$h_s = \frac{A_{hc} R L}{2}$

$A_{hc} = \frac{Z\, I\, S_a}{2\, R\, g}$

A_{hc} = Design horizontal seismic coefficient

h_s = 0.086139 m

Therefore, Inner height of the cell = 0.145955 m

Earthquake records

Two earthquake records have been chosen to be used as excitation when the structure is analyzed. For each earthquake, there are two horizontal components and one vertical component. The vertical component is ignored in the analysis. Since the structure is not symmetrical in plan, the horizontal acceleration records have to be switched between the x and y axis, i.e., the horizontal acceleration record in the x direction in one load case will be switched to the y direction in the second load case. Therefore, each earthquake will consist of two load cases. These can be named as time history 1 (**TH1**) and time history 2 (**TH2**) in the analysis part. The details of the earthquakes used for the analysis are listed below

Table-2 Earthquake records

No	Earthquake	Station name	Moment magnitude	PGA (g)
1	Kobe(1995)	Nishi Akashi	6.9	0.386
2	Loma Prieta(1989)	Hollister-south Street and pine drive	7	0.368

KOBE EARTHQUAKE

4.3.1 Storey displacements

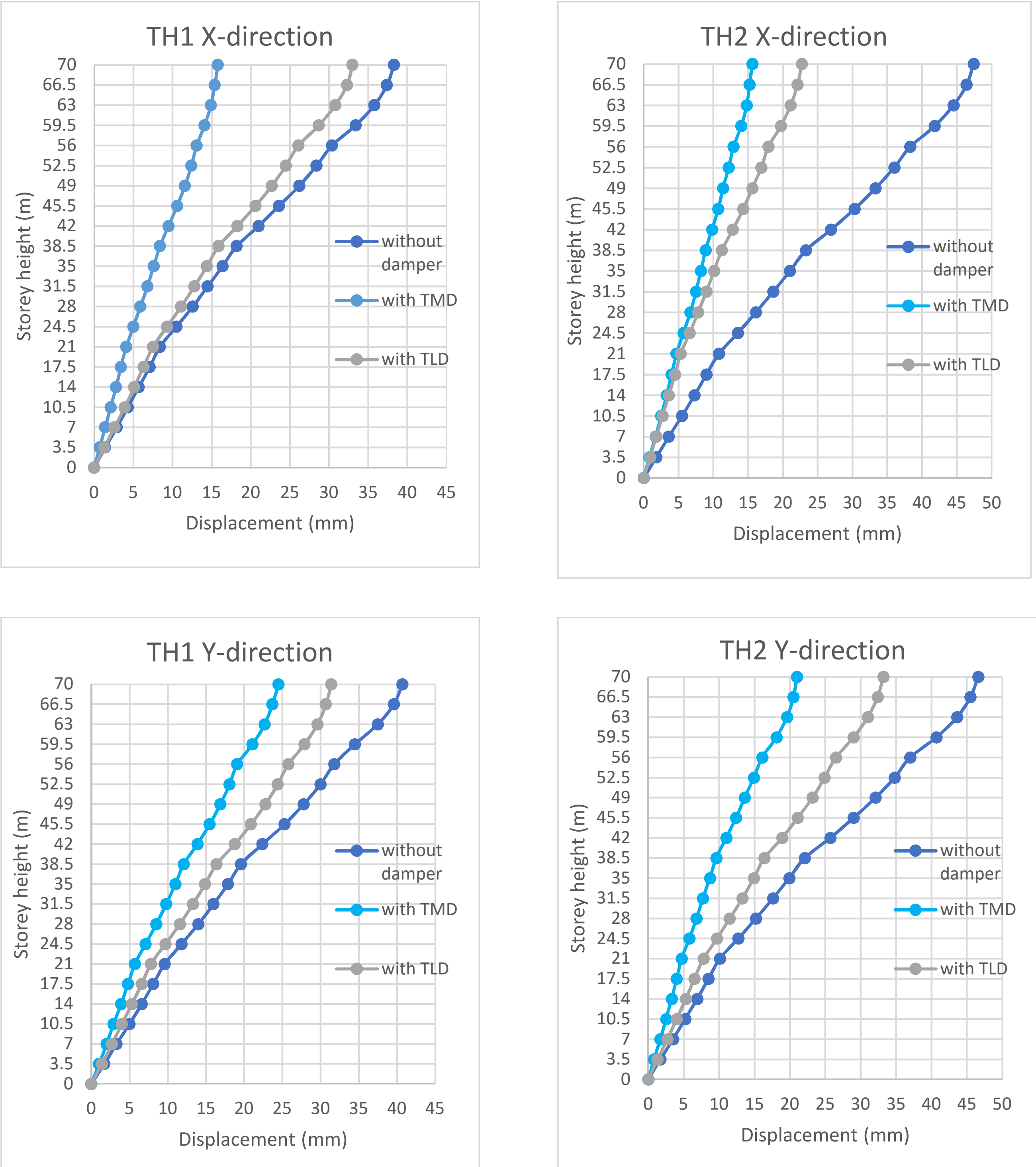


Fig. 2. Storey displacement vs storey height

LOMA PRIETA EARTHQUAKE

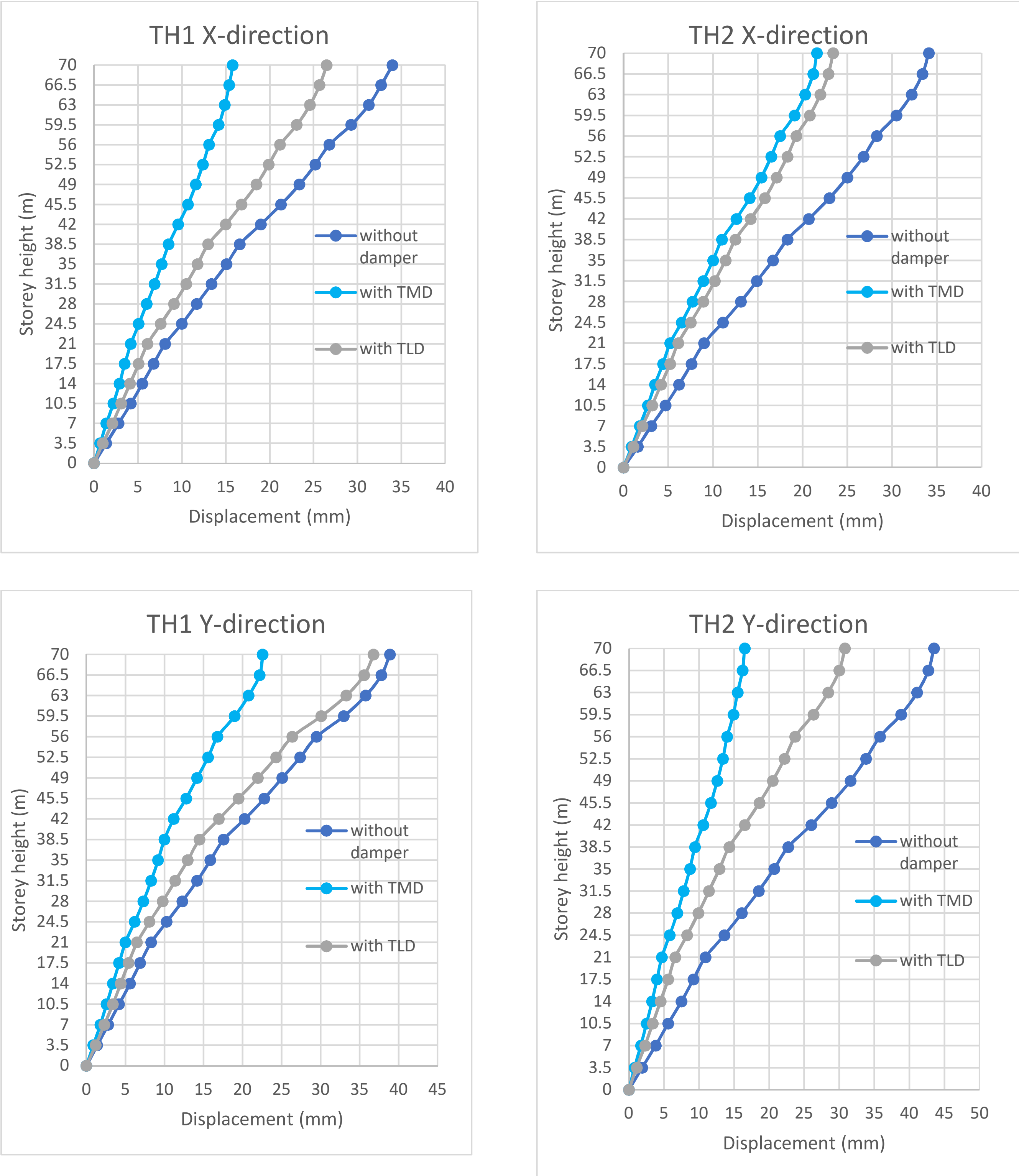


Fig. 2. Storey displacement vs storey height

Conclusion

This study focused on the structural response reduction capacity of the tuned mass damper and tuned liquid damper as passive vibration control devices. Three-dimensional models were created and the response reduction capacity was evaluated in SAP 2000. The optimum parameters of TMD and TLD were obtained from the work of Tsai and Lin and IS 1893 Part 2, respectively. The results obtained from the analysis are as follows:

1. The application of TMD and TLD in the structure produced a considerable reduction in response when subjected to the earthquake acceleration time history records.
2. The percentage reduction in the structural responses was not directly proportional to the mass ratios, but had a steep rising stage till after which the increase in percentage reduction in response is insignificant with respect to the inputted damper mass.
3. Optimal performance is achieved when the dampers are placed in the storey having maximum displacement, in the case of regular buildings at the top storey.
4. The maximum displacement of the damper mass is an important factor in the design of TMD. It can be seen from the results that for dampers of lower mass, the relative displacement of the damper is higher and for dampers of higher mass, the relative displacement of the damper is lower.
5. The overall performance of the TLD is inferior compared to the performance of TMD. This is attributed to the fact that the damping coefficient value used in modelling the TLD is negligible compared to the value used in TMD.
6. The size of the TLD cells is proportional to the period of the structure which is to be controlled. Therefore, structures having large time periods will be equipped with a smaller number of larger tanks and vice versa.

Disclosures

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References

1. Nimmy Sen Sebastian, Dr. Abey.E. Thomas, Jency Sara Kurian (2017). “Seismic analysis of elevated water tank in a framed building.”
2. Nishant Kishore Rai, G.R. Reddy, V. Venkatraj (2013). “Tuned liquid sloshing water damper: A robust device for seismic retrofitting.”
3. Mr. Aakash Bikram Rana, Mr. Shubhesh Bista, Mr. Prashant Sunagar (2018). “Analysis of Tuned Liquid Damper (TLD) in controlling earthquake response of a building using SAP2000.”
4. Blachandar M, Vinod Y (2018). “Control of vibrations in building due to seismic force using Tuned Mass Damper.”
5. H.A. Admane, Y.D. Shermale, R.S. Jaiswal (2017). “Application of Tuned Mass Damper for vibration control of multistoried building under seismic excitation.”
6. Mr. Ashish A. Mohite, Prof. G.R. Patil (2015). “Earthquake analysis of tall buildings with Tuned Mass Damper.”
7. Raveesh R M, Sahana T S (2014). “Effect of Tuned Mass Damper on multistoried RC framed structures.”
8. John R. Sladek, Richard. E. Klingner (1982). “Effect of Tuned Mass Damper on seismic response.”
9. Thakur V.M, Pachpor P.D (2012). “Seismic Analysis of multistoried building with TMD (Tuned Mass Damper).”
10. Haitham Mohamed Khalaf, K. Sandeep Kumar (2016). “Analysis and design of multi storied building for vertical and horizontal loading with and without damper using SAP2000.”
11. Jerome Connor, Simon Laflamme (2014). “Structural Motion Engineering.”
12. Y. Fujino, L.M. Sun (1992). “Vibration control by Multiple Tuned Liquid Dampers (MLTDs).”
13. IS 1893 (Part 1) (2016). “Criteria for Earthquake resistant design of structures Part 1 General provisions and buildings.”
14. IS 1893(Part 2) (2014). “Criteria for Earthquake resistant design of structures Part 2 Liquid retaining tanks.”
15. Jong Wan Hu, Kobra Naeim, Iman Mansouri, Hamed Rahman Shokrgozar (2019). “Efficiency of TMDs and TLDs for low-rise and mid-rise buildings subjected to near field and far field earthquakes.”