A COMPARATIVE STUDY ON SEISMIC RESPONSE MITIGATION OF BASE ISOLATED BUILDINGS

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Abstract

The objective of this article is to compare the effectiveness of tuned mass dampers (TMDs) with that of a swimming pool designed as a tuned liquid dampers (TLDs) for seismic response mitigation of a reinforced concrete (RC) base isolated (BI) building. The effect of amplitude of ground motion in their effectiveness is investigated. Furthermore, the effect of depth to length of the TLD is investigated. Base shear, floor acceleration and displacement response of the building with and without the TMD/TLD schemes are studied. It is noticed that that vibration mitigation of BI building is achieved by installing TLDs or TMDs. However, TLD is more effective as compared to the TMD to mitigate the seismic response of BI building. It demands for a TLD system having higher water level to produce better performance. Further, it is seen that having the TLD at ground floor is more effective than adding at top floor. However, this is not the case for a TMD system.

Keywords: Base isolated building; Earthquake; Tuned mass damper; Tuned liquid damper

1. Introduction

Over the recent couple of decades, the structural vibration mitigation techniques have been simplified for reduction of their dynamic response caused by different natural hazards. Tuned mass dampers (TMDs) and tuned liquid dampers (TLDs) are one of the common control methods used for response mitigation of structures under dynamic loadings. Their applications in various situations and loads have been addressed by several researchers [1-20]. A detailed literature survey on passive TMDs is presented in Elias and Matsagar [21].
Base-isolation (BI) has been one of the most common and recognized technique of earthquake response mitigation. This technique depends on friction pendulum (FP) or lead rubber bearings (LRB) at the base of the structure. BI technique performs by making the isolated structure more flexible at the base, so decreasing acceleration response, and consequently base shear force on the structure. Because of increased flexibility, displacement demand on the structure gets amplified, and extra damping is required to keep displacement demand in suitable limits. There is a tradeoff between the extent to which acceleration and displacement demand can be controlled by BI system combined with additional damping devices [22].
TMD is efficient in response mitigation of BI systems if the loading frequency is lower than the natural frequency of the structure [23]. Better efficiency is expected by optimally designed non-traditional TMD for reducing of earthquake response of BI buildings [24]. Recently use of TMD with inerter (TMDi) presented to have effective performance to mitigate earthquake response of BI buildings [25-28]. Effectiveness of single tuned mass dampers (STMD), multiple tuned mass dampers (MTMD) and distributed multiple tuned mass dampers (d-MTMD) on seismic response control of BI buildings was investigated by Stanikzai et al. [29, 30]. They found that d-MTMDs were more effective and practical than other schemes. Use of a tuned liquid damper (TLD) as a cost-effective method to reduce the wind induced vibrations of BI structures is presented by Love et al [31]. Very recently a comparison of TMD, a New TMD (New TMD) and a tuned liquid column damper (TLCD), for response mitigation of a BI structure is considered [32].
Past studies do not contain a comparative investigation on effectiveness of TMDs and TLD in response control of BI buildings under earthquake ground motions. It is therefore necessary to consider this comparative study to understand the effectiveness of TMD and TLD in response control of BI building.

2. Mathematical model

Figure 1 demonstrates the mathematical model for *N*-story BI building a) without TMD/TLD, b) installed with a TMD at top floor, and c) installed with a TLD at top floor. The floor masses m_1 to m_N are lumped masses, whereas, m_b and m_d are mass of BI and TMD respectively. TMD consists of mass (m_d), stiffness (k_d) and damping (c_d) is attached at top floor. The displacement of the floors is denoted by X_1 to X_N and X_b and x_d are the displacement of BI and TMD respectively. The stiffness of floors is denoted by k_1 to k_N and damping of fixed base structure was computed using Rayleigh approach. Design of BI building is done based on methods described in References [33, 34]. Elias and Matsagar [35] provided design procedure for single TMD, which is adopted in this study. In order to design the TLD a method described in Reference [17] is adopted. The governing equation of motion for the system under consideration can be written as

$$[M]\{\ddot{x}(t)\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = -[M]\{r\}\{\ddot{x}_g\} \tag{1}$$

where $[M]$, $[C]$ and $[K]$ are the mass, damping and stiffness matrices of the structure $\{x\} = \{X_1, X_2, \cdots X_N, X_b, \cdots x_{T1}, x_{T2}, \cdots x_{Tn}\}^T$, $\dot{x}$ and $\ddot{x}$ are the unknown relative (floor, isolator and TMD) displacement, velocity and acceleration vectors, respectively; $\ddot{x}_g$ is earthquake ground acceleration and r is the vector of influence coefficients. The matrices of hybrid system can be found in Reference [30].

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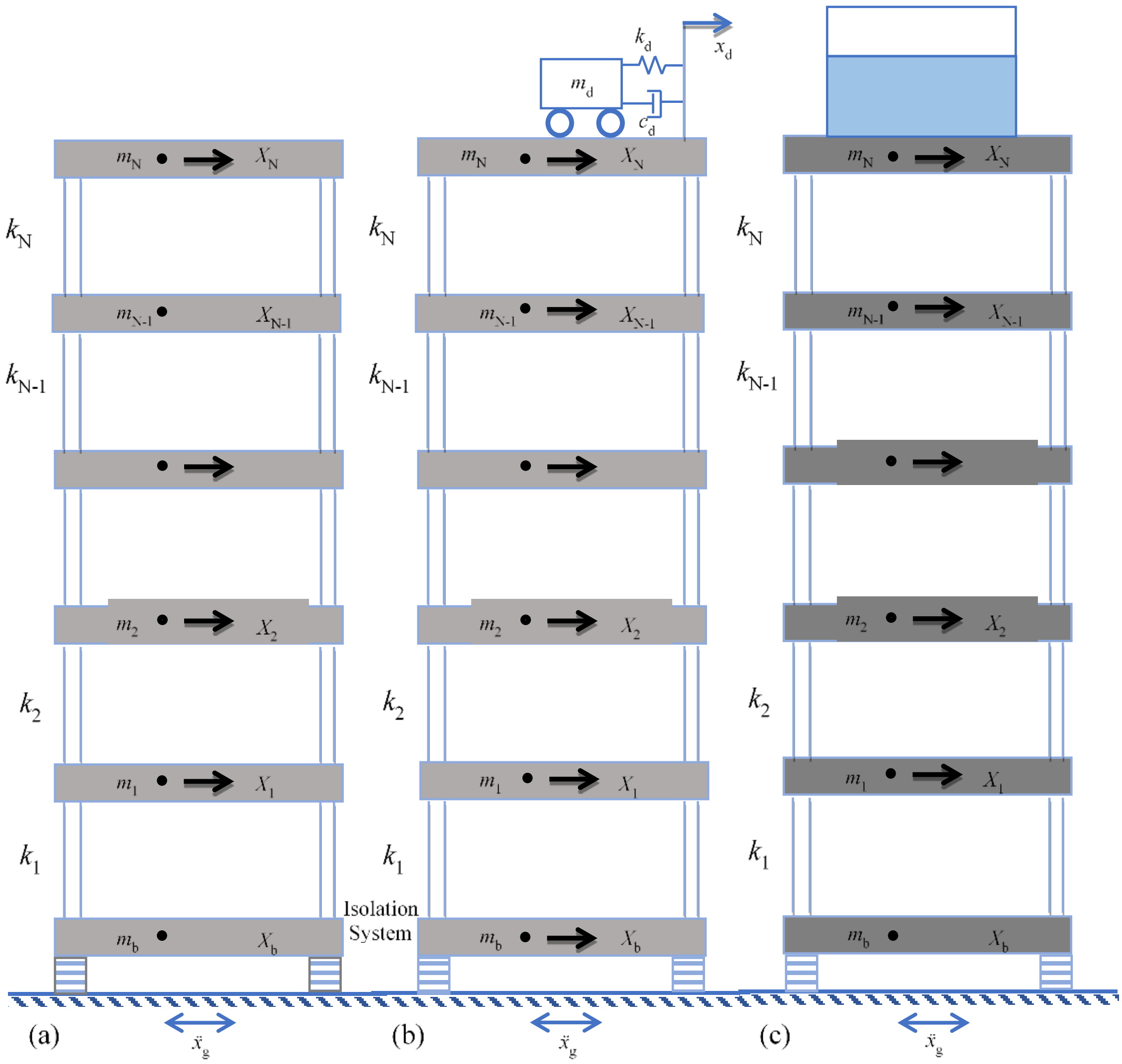

Fig. 1 – Mathematical model of *N*-story (a) BI, (b) BI + STMD at top floor, (c) BI + TLD at top floor

3. Numerical Study

In this study a five-story reinforced concrete (RC) building is taken from Reference [34]. The design period for BI is decided to be 2.5 sec. Each floor assumed to have mass of 20.4 ton and stiffness of 39700 kN/m. The damping ratio is assumed to be 2% to be used for estimation of multiplier to mass and stiffness matrices following Rayleigh approach. The damping ratio for BI is assumed to be 5% and yielding displacement of 5 cm. The yield restoring shear-force of damper system is 7.5% of total building weight. It is also important to consider the fact that that TLD assumed to be a swimming pool. Therefore, the height of water can be more than 2 meters for swimming pool inside an apartment. TLD is designed to have a length of 5.5 meters, a width of 3 meters and a water height of 1.8 meters. These dimensions allow the hybrid system to have a period of about 2.27 seconds. A TMD designed to have similar mass of the TLD. The analysis is carried for BI building, BI building equipped by a TMD, BI building equipped by a TMD under the Bucharest, 1977; Imperial Valley, 1979; Panisler, 1983; and Mexico City, 1995 (Figures 2 through 5). Figures 2 through 5 show the variation of response reduction by increasing the depth of water in the swimming pool.

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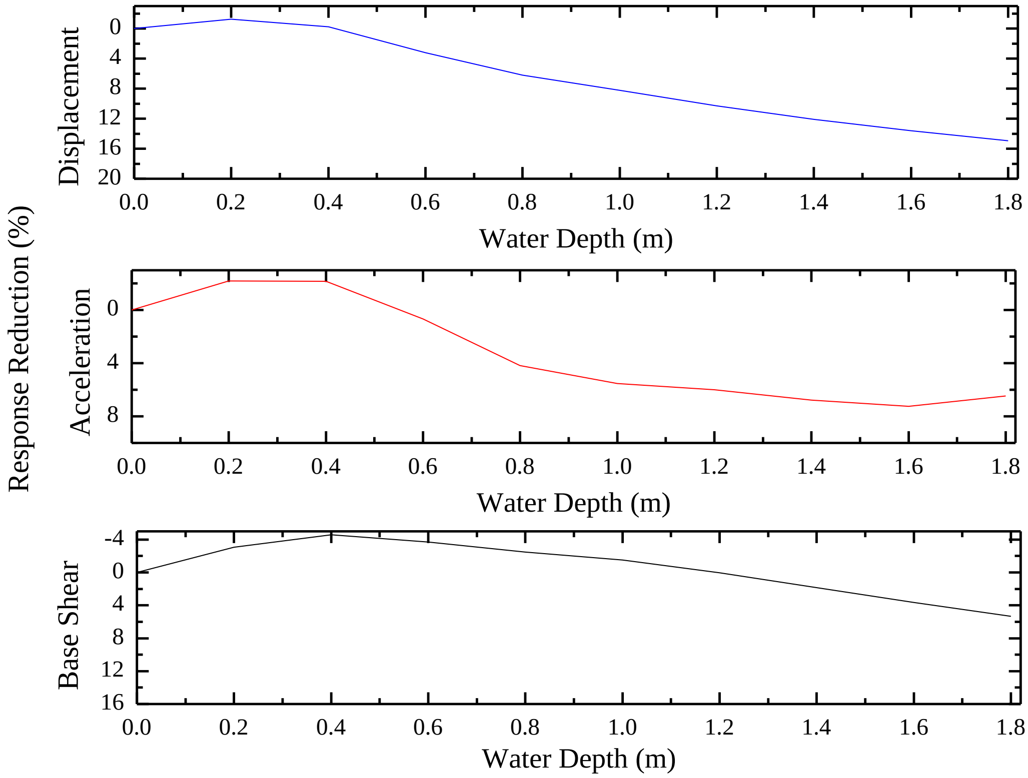

Fig. 2 – Variation of response reduction by increasing the water depth under Bucharest, 1977.

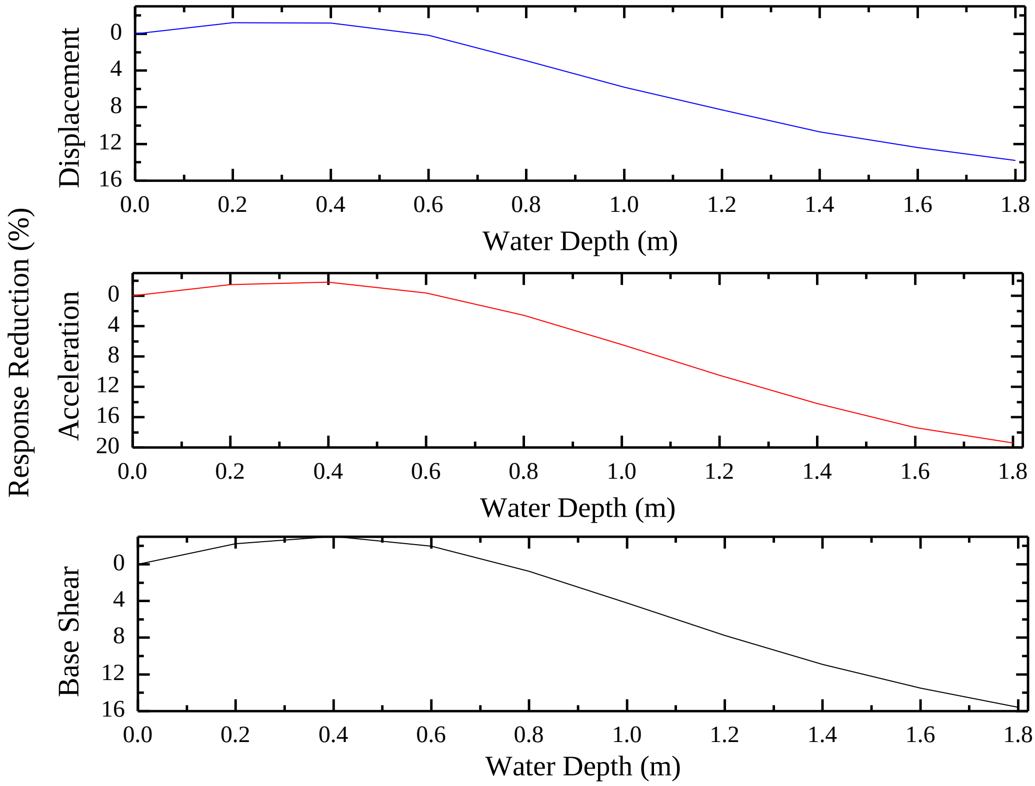

Fig. 3 – Variation of response reduction by increasing the water depth under Imperial Valley, 1979.

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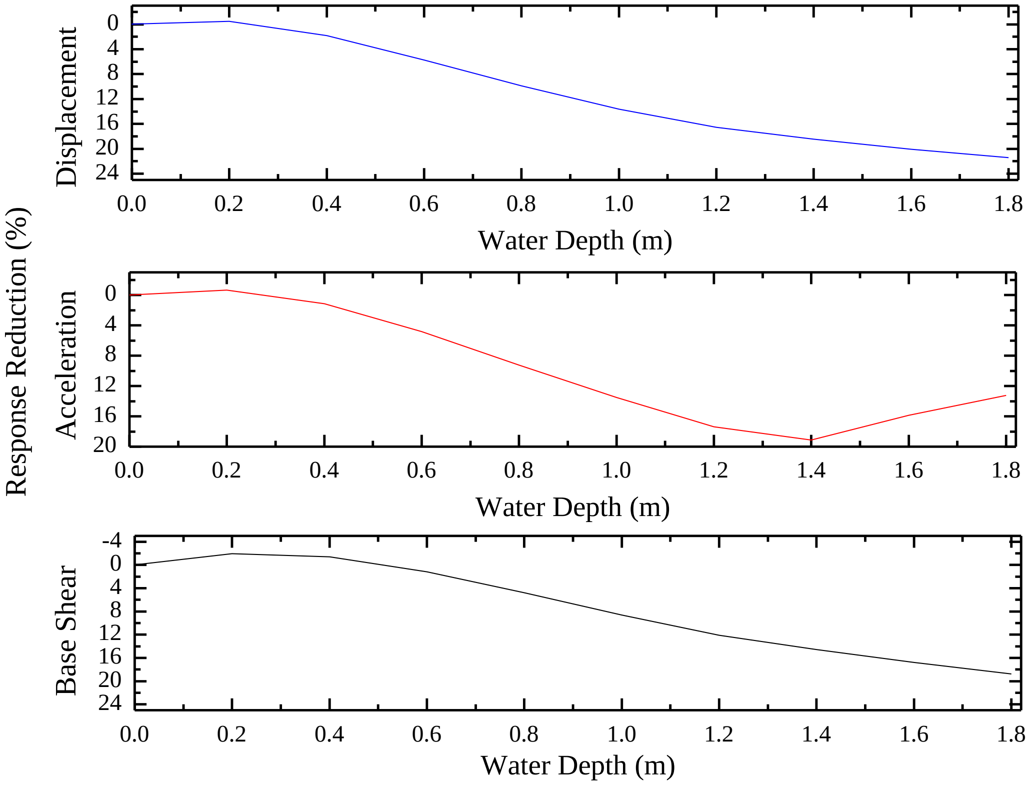

Fig. 4 – Variation of response reduction by increasing the water depth under Panisler, 1983.

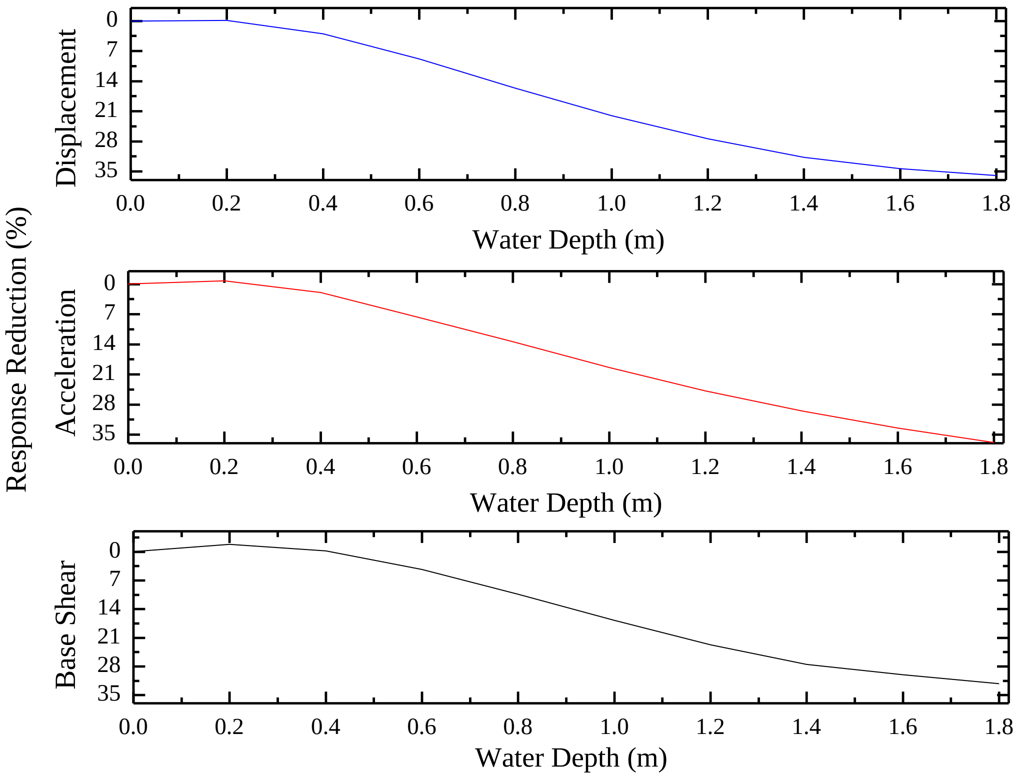

Fig. 5 – Variation of response reduction by increasing the water depth under Mexico City, 1995.

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It is important to know the response of the BI building equipped by swimming pool according to the water level of the pool, because it will not always be full of water. The depth is not increased behind 1.8 meters as it will not practical to have that kind of swimming pool. It is noticed that all kind of response under all considered earthquakes are reduced.

Figures 6 through 9 show the variation of response reduction by changing the location of the swimming pool. Its location moved from ground which was assumed to be on BI to the top floor of building. Although, practically it is not possible to have it on BI level, only based on mathematical formulation analysis carried out. It appears from Figure 3, that except the ground level, other positions will not have significant effect on performance of a TLD. This is the due to the fact that BI buildings, superstructure is acting as a rigid body and experiences same displacement throughout the height. This is in good agreement with findings earlier presented in References [29, 30]. Therefore, it is concluded that the TLD can be placed at any location of the selected BI building while subjected to earthquakes.

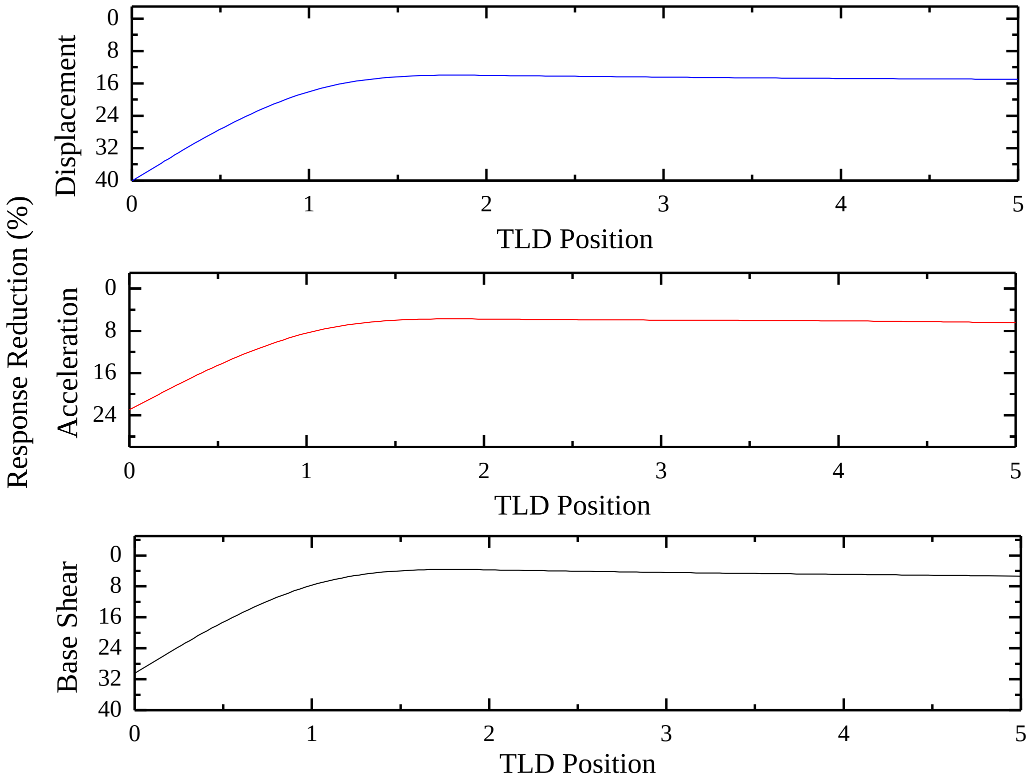

Fig. 6 – Variation of response reduction by changing the position of TLD under Bucharest, 1977.

Figures 10 through 13 demonstrate the comparison of TLD and TMD in response mitigation of BI building under earthquakes. The peak ground acceleration (PGA) of the selected earthquakes are varied to check its influences on effectiveness of TLD and TMD. The variation in increase of response is linearly, this is due to consideration of bi-linear model of BI model, which is not able to provide the nonlinear increase or decrease in response. Although, this approach is well-accepted but adopting the Wen model is more accurate. However, for this study to present the pattern this simpler approach is adopted. It is noticed in the Figures 10 through 13 that higher the PGA, higher the response of BI, and slightly more the performance TLD and TMD. Generally, TLD is providing more effectiveness as compared to the TMD in response control of BI building under the selected earthquakes.

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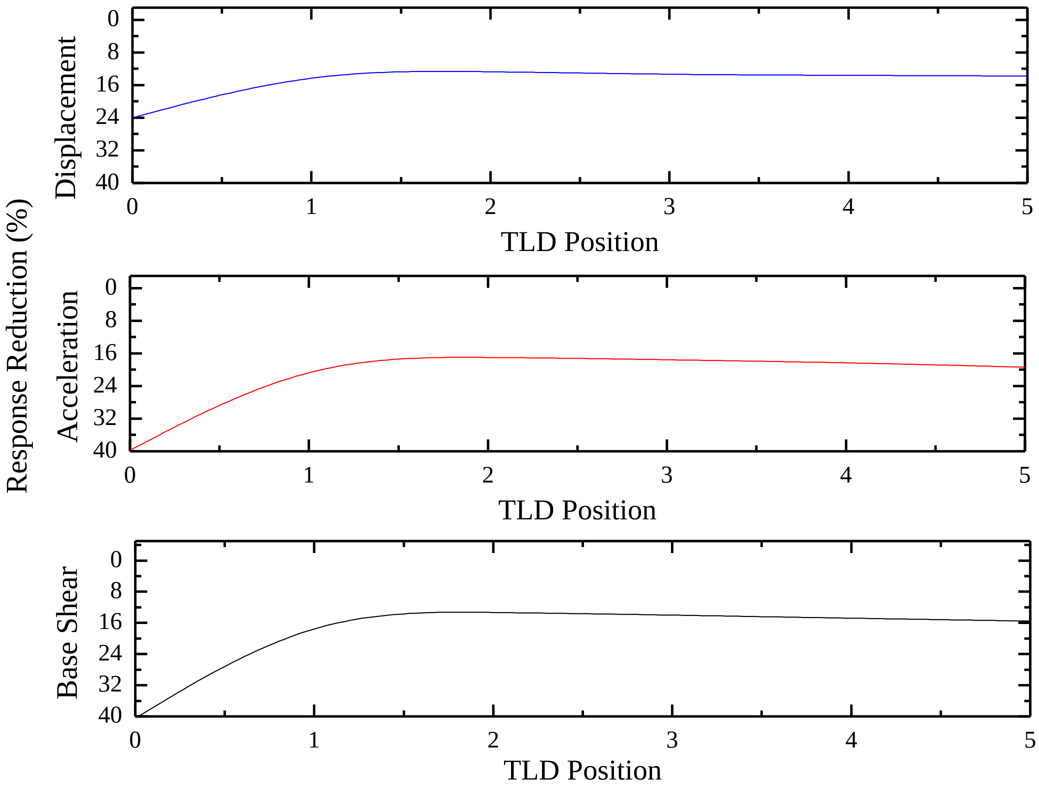

Fig. 7 – Variation of response reduction by changing the position of TLD under Imperial Valley, 1979.

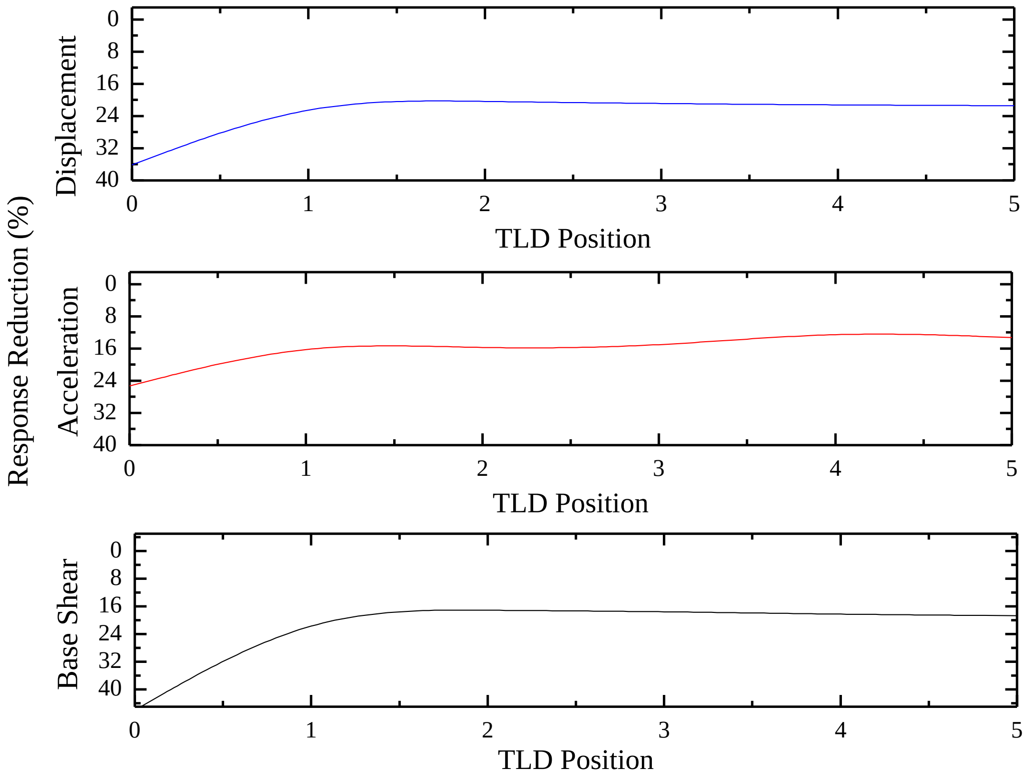

Fig. 8 – Variation of response reduction by changing the position of TLD under Panisler, 1983.

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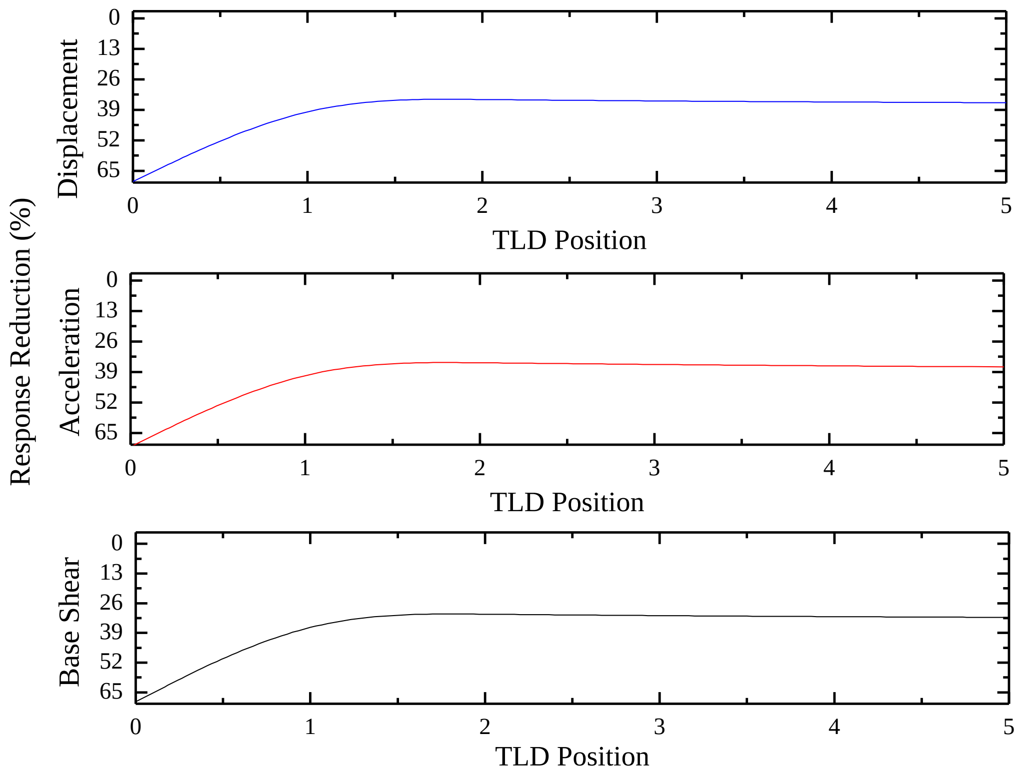

Fig. 9 – Variation of response reduction by changing the position of TLD under Mexico City, 1995.

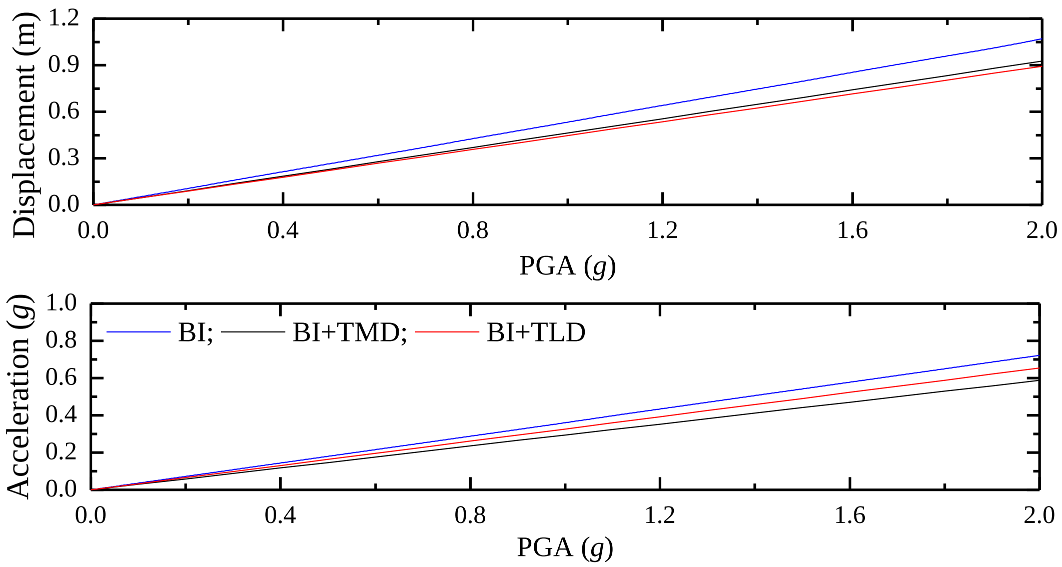

Fig. 10 – Variation of response of BI, BI+TMD, BI+TLD by changing the PGA of Bucharest, 1977

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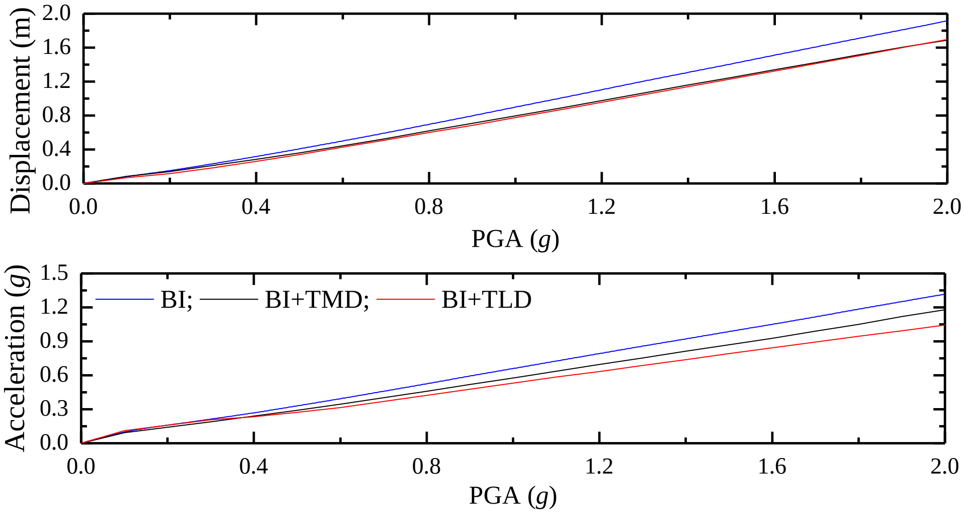

Fig. 11 – Variation of response of BI, BI+TMD, BI+TLD by changing the PGA of Imperial Valley, 1979.

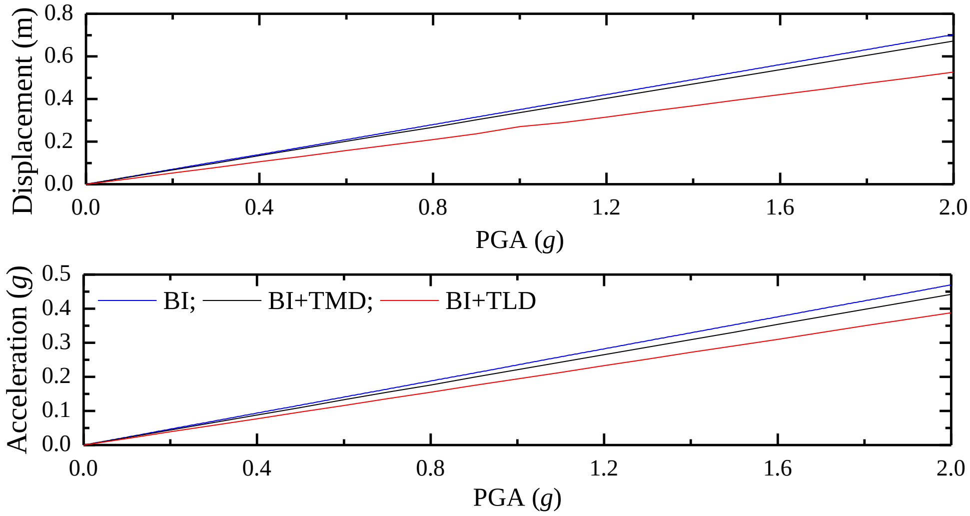

Fig. 12 – Variation of response of BI, BI+TMD, BI+TLD by changing the PGA of Panisler, 1983.

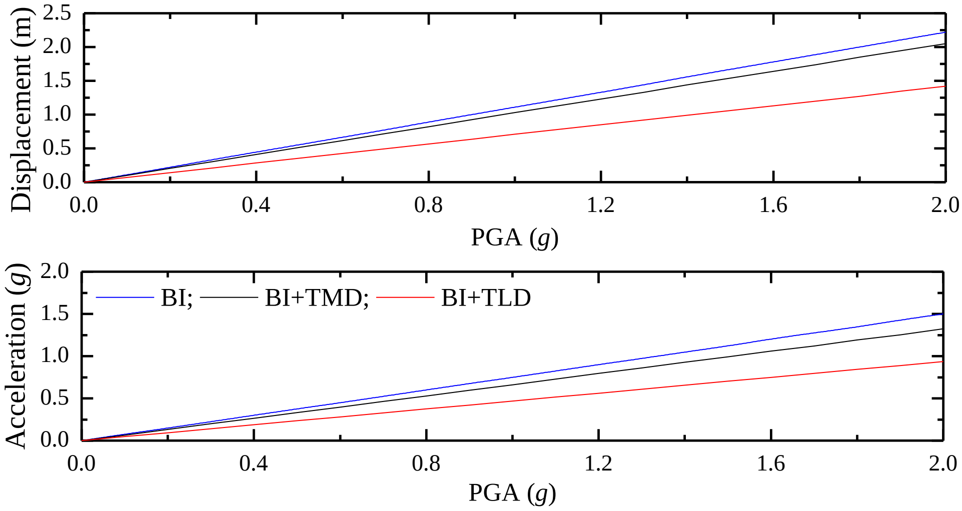

Fig. 13 – Variation of response of BI, BI+TMD, BI+TLD by changing the PGA of Mexico City, 1995.

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4. Conclusions

A comparative study on effectiveness of tuned liquid damper (TLD) and tuned mass damper (TMD) for response mitigation of a five-story reinforced concrete (RC) building is presented. Based on the results discussed following conclusions can be drawn:

1. TLD is more effective as compared to the TMD to mitigate the seismic response of BI building.
2. It demands for a TLD system having higher water level to produce better performance.
3. It is seen that having the TLD at ground floor is more effective than adding at top floor. However, this is not the case for a TMD system.

4. Acknowledgements

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6. References

[1] Greco R, Marano GC (2013): Optimum design of Tuned Mass Dampers by displacement and energy perspectives. *Soil Dynamics and Earthquake Engineering*, **49**, 243-253.

[2] Longarini N, Zucca M (2014): A chimney's seismic assessment by a tuned mass damper. *Engineering Structures*, **79**, 290-296.

[3] Reggio A, Angelis MD (2015): Optimal energy‐based seismic design of non‐conventional Tuned Mass Damper (TMD) implemented via inter‐story isolation. *Earthquake Engineering & Structural Dynamics*, **44** (10), 1623-1642.

[4] Lu Z, Li K, Zhou Y (2018): Comparative Studies on Structures with a Tuned Mass Damper and a Particle Damper. *Journal of Aerospace Engineering*, **31** (6), 04018090.

[5] Rezaee M, Aly AM (2018): Vibration Control in Wind Turbines to Achieve De-sired System-Level Performance under Single and Multiple Hazard Loadings, *Structural Control and Health Monitoring*, DOI:10.1002/stc.2261.

[6] Wang C, Shi W (2019): Optimal design and application of a multiple tuned mass damper system for an in-service footbridge. *Sustainability*, **11** (10), 2801.

[7] Cao L, Li C (2019): Tuned tandem mass dampers‐inerters with broadband high effectiveness for structures under white noise base excitations. *Structural Control and Health Monitoring*, **26** (4), e2319.

[8] Elias S, Matsagar V, Datta TK (2016): Effectiveness of distributed tuned mass dampers for multi-mode control of chimney under earthquakes. *Engineering Structures*, **124**, 1-16.

[9] Elias S, Matsagar V, Datta TK (2017): Distributed tuned mass dampers for multi-mode control of benchmark building under seismic excitations. *Journal of Earthquake Engineering*, 1-36.

[10] Elias S, Matsagar V, Datta TK (2019a): Along‐wind response control of chimneys with distributed multiple tuned mass dampers. *Structural Control and Health Monitoring*, **26** (1), e2275.

[11] Elias S, Matsagar V, Datta TK (2019b): Dynamic response control of a wind-excited tall building with distributed multiple tuned mass dampers. *International Journal of Structural Stability and Dynamics*, **19** (06), 1950059.

[12] Gill D, Elias S, Steinbrecher A, Schröder C, Matsagar V (2017): Robustness of multi-mode control using tuned mass dampers for seismically excited structures. *Bulletin of Earthquake Engineering*, **15** (12), 5579-5603.

[13] Elias S (2018): Seismic energy assessment of buildings with tuned vibration absorbers. *Shock and Vibration*, **2018**.

[14] Elias S (2019): Effect of SSI on vibration control of structures with tuned vibration absorbers. *Shock and Vibration*, **2019**.

[15] Elias S, Matsagar V (2019): Seismic vulnerability of non-linear building with distributed multiple tuned vibration absorbers, *Structure and Infrastructure Engineering*, 10.1080/15732479.2019.1602149.

[16] Matin A, Elias S, Matsagar V (2019): Distributed multiple tuned mass dampers for seismic response control in bridges. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, 1-18.

[17] Tait MJ (2008): Modelling and preliminary design of a structure-TLD system. *Engineering Structures*, **30** (10), 2644-2655.

[18] Tait MJ, El Damatty AA, Isyumov N, Siddique MR (2005): Numerical flow models to simulate tuned liquid dampers (TLD) with slat screens. *Journal of Fluids and Structures*, **20** (8), 1007-1023.

[19] Love JS, Tait MJ (2010): Nonlinear simulation of a tuned liquid damper with damping screens using a modal expansion technique. *Journal of Fluids and Structures*, **26** (7-8), 1058-1077.

[20] Tait MJ, Isyumov N, El Damatty AA (2008): Performance of tuned liquid dampers. *Journal of Engineering Mechanics*, **134** (5), 417-427.

[21] Elias S, Matsagar V (2017): Research developments in vibration control of structures using passive tuned mass dampers. *Annual Reviews in Control*, **44**, 129-156.

[22] Zelleke DH, Elias S, Matsagar VA, Jain AK (2015): Supplemental dampers in base-isolated buildings to mitigate large isolator displacement under earthquake excitations. *Bulletin of the New Zealand Society for Earthquake Engineering*, **48** (2), 100-117.

[23] Tsai H (1995): The effect of tuned-mass dampers on the seismic response of base-isolated structures. *International Journal of Solid Structures*, **32** (8/9), 1199-1210.

[24] Xiang P, Nishitani A (2014): Optimally design for more effective tuned mass damper and its application to base-isolated buildings. *Structural Control and Health Monitoring*, **21** (1), 98-114.

[25] De Domenico D, Ricciardi G (2018a): Optimal design and seismic performance of tuned mass damper inerter (TMDI) for structures with nonlinear base isolation systems. *Earthquake Engineering & Structural Dynamics*, **47** (12), 2539-2560.

[26] De Domenico D, Ricciardi G (2018c) An enhanced base isolation system equipped with optimal tuned mass damper inerter (TMDI). *Earthquake Engineering & Structural Dynamics*, **47** (5), 1169-1192.

[27] De Domenico D, Deastra P, Ricciardi G, Sims ND, Wagg DJ (2018): Novel fluid inerter based tuned mass dampers for optimised structural control of base-isolated buildings. *Journal of the Franklin Institute*,

[28] De Domenico D, Ricciardi G (2018b): Earthquake-resilient design of base isolated buildings with TMD at basement: Application to a case study. *Soil Dynamics and Earthquake Engineering*, **113**, 503-521.

[29] Stanikzai MH, Elias S, Matsagar VA, Jain AK (2019b): Seismic response control of base-isolated buildings using tuned mass damper. *Australian Journal of Structural Engineering*, 1-12.

[30] Stanikzai MH, Elias S, Matsagar VA, Jain AK (2019a): Seismic response control of base‐isolated buildings using multiple tuned mass dampers. *The Structural Design of Tall and Special Buildings*, **28** (3), e1576.

[31] Love JS, Tait MJ, Toopchi-Nezhad H (2011): A hybrid structural control system using a tuned liquid damper to reduce the wind induced motion of a base isolated structure. *Engineering Structures*, **33** (3), 738-746.

[32] Di Matteo A, Masnata C, Pirrotta A (2019): Hybrid passive control strategies for reducing the displacements at the base of seismic isolated structures. *Frontiers in Built Environment*, **5**, 132.

[33] Matsagar VA, Jangid RS (2004): Influence of isolator characteristics on the response of base-isolated structures. *Engineering Structures*, **26** (12), 1735-1749.

[34] Jangid RS (2007): Optimum lead–rubber isolation bearings for near-fault motions. *Engineering Structures*, **29** (10), 2503-2513.

[35] Elias S, Matsagar V (2018): Wind response control of tall buildings with a tuned mass damper. *Journal of Building Engineering*, **15**, 51-60.

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