Parametric study of optimal design parameters of tuned mass dampers for mitigation of seismic response of buildings

S. Elias[1], R. Rupakhety [2], S. Ólafsson [3]

[1] *Post PhD Scholar, Earthquake Engineering Research Centre, Faculty of Civil and Environmental Engineering, School of Engineering and Natural Science, University of Iceland, Austurvegur 2a, 800 Selfoss, Iceland, said@hi.is*
[2] *Professor, Earthquake Engineering Research Centre, Faculty of Civil and Environmental Engineering, School of Engineering and Natural Science, University of Iceland, Austurvegur 2a, 800 Selfoss, Iceland, rajesh@hi.is*
[3] *Professor, Earthquake Engineering Research Centre, Faculty of Civil and Environmental Engineering, School of Engineering and Natural Science, University of Iceland, Austurvegur 2a, 800 Selfoss, Iceland, simon@hi.is*
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Abstract

Available design procedures for TMDs restrict the device being sensitive to excitation frequencies. However, earthquake ground motions contain multiple frequencies, and the available designs are not robust for earthquake response mitigation. This article presents a simplified procedure to design a novel distributed multiple TMDs (d-MTMDs) for response mitigation of reinforced concrete (RC) buildings while subjected to earthquake excitations compatible with spectrum given in Eurocode 8. In this study, recorded ground motions are scaled and modified to make them compatible to the Eurocode 8 response spectrum. The parameters of the d-MTMDs optimized by detailed parametric study. The performance of the d-MTMDs is compared with those of single TMD (STMD) and MTMDs placed at top floor. Floor displacement, and acceleration are examined to access the effectiveness of the control schemes. It is noticed that STMD and MTMDs designed based on available optimal solutions are not effective for vibration mitigation of buildings under ground motions compatible to the Eurocode 8 spectrum. However, the d-MTMDs with optimal parameters determined by detailed parametric studies are more effective for response reduction of buildings under ground motions compatible to the spectrum of Eurocode 8. It shows a demand for a new optimization technique for designing TMD schemes for response mitigation of buildings for site specific earthquake ground motion.

Keywords: Building; Earthquake; Tuned mass damper (TMD); Distributed multiple TMDs

1. Introduction

Use of passive control devices such as tuned mass dampers (TMDs), tuned liquid dampers (TLDs), etc., has been explored in many structures and loading scenarios [1-20]. A detailed literature survey on passive TMDs is presented in Elias and Matsagar [21]. TMDs have also been found useful in mitigation of seismic response in base-isolated (BI) buildings.

TMD is efficient in response mitigation of BI systems if the loading frequency is lower than the natural frequency of the structure [23]. 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. [24, 25]. They found that d-MTMDs were more effective and practical than other schemes.

Past studies on seismic response mitigation of structures through TMDs rely on simplified equations for tuning the frequencies and damping ratios of the devices. Such equations are mostly valid for harmonic base motion, while their validity for transient motion like the ones caused by earthquakes is questionable. In lack of analytical methods for optimizing the TMDs for transient ground shaking, we explore parametric methods to optimize the parameters and investigate the effectiveness of the devices in seismic response control.

2. Mathematical model

Figure 1 shows the mathematical model of a *N*-story building a) without TMD schemes (NC), b) installed with a TMD at the top floor (STMD), c) installed with multiple TMDs at the top floor, and d) installed with distributed TMDs on different floors (d-MTMDs). The floor masses m_1 to m_N are lumped , whereas, m_{d1} to m_{dn} are the masses of the *n* TMDs, respectively. Each TMD is attached to the floor by a spring with stiffness (k_d) and dashpot with damping (c_d). The displacement of the floors is denoted by X_1 to X_N respectively from first to top floor, and x_d is the displacement of TMD.

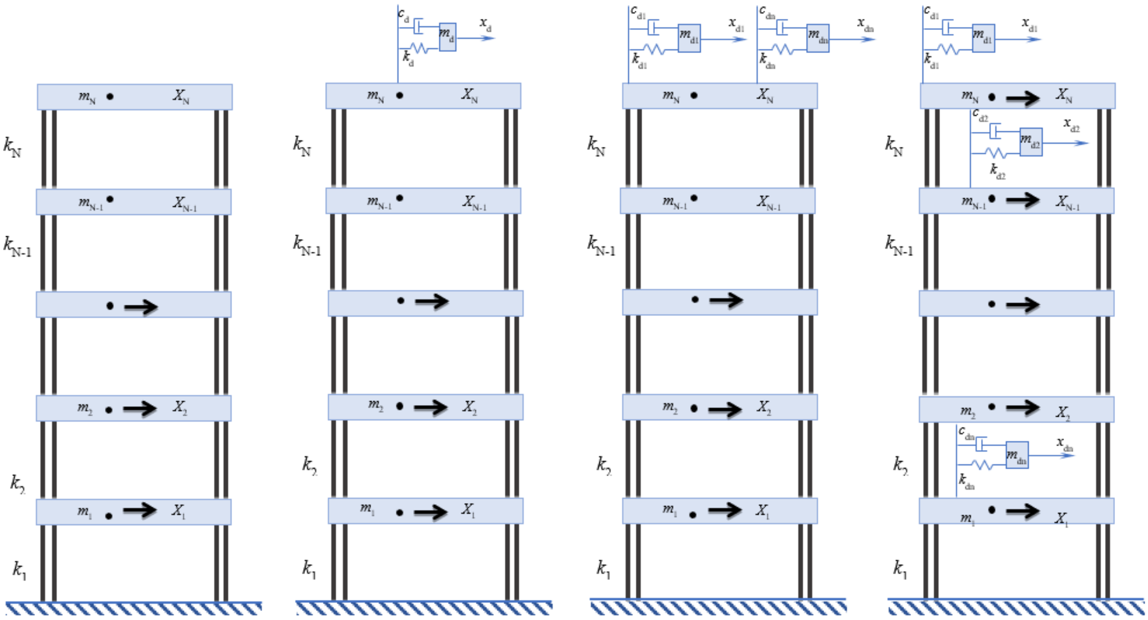

Fig. 1 – Mathematical model of *N*-story (a) NC, (b) STMD at top floor, (c) MTMDs at top floor and (d) d-MTMDs at different floors

The stiffness of floors is denoted by k_1 to k_N and damping of the fixed base structure was computed using Rayleigh approach. Preliminary design of the TMDs is based on the methods described in Elias and Matsagar [15, 27].

3. Numerical Study

In this study a ten-story reinforced concrete (RC) building is taken from a study by Han et al. [26]. Each floor is assumed to have a mass of 360 ton and stiffness of 650000 kN/m. The damping ratio is assumed is be 3% and 9% for the first two modes. Response analysis is carried out using the 1976 Friuli Earthquake recoded at the Tolmezzo-Diga Ambiesta station, and the 2000 South Iceland Earthquake recorded at the Flagbjarnarholt station. These ground motions are scaled and modified to make them compatible to the Eurocode 8 response spectrum. The 5% damped pseudo acceleration spectra of these ground motions are shown in Figures 2 and 3. Acceleration time history of both ground motions are shown in Figure 4.

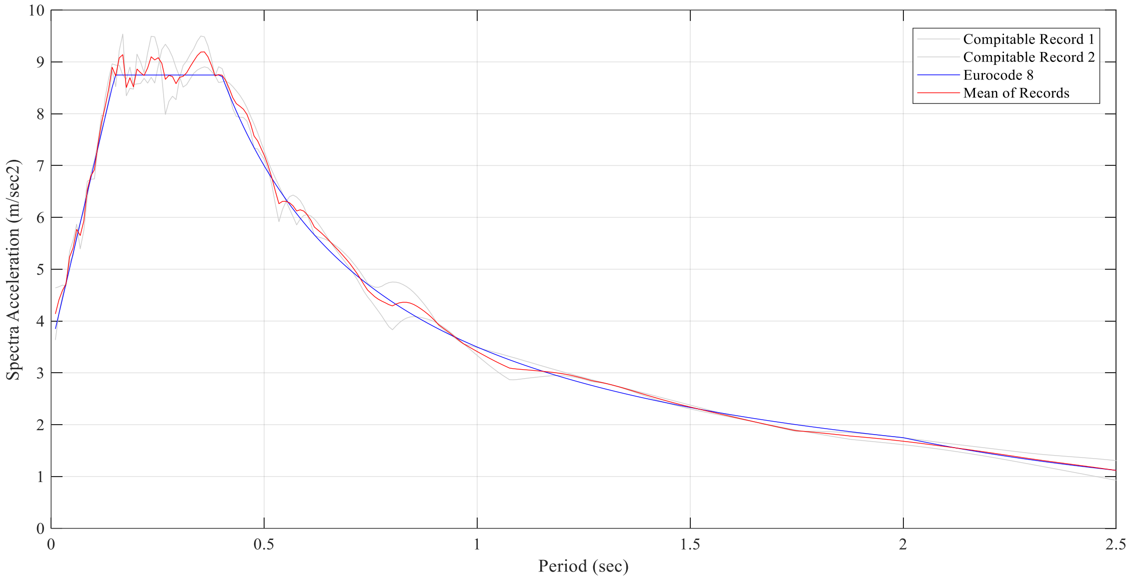

Fig. 2 – Eurocode 8 compared with the scaled ground motion from the 1976 Friuli Earthquake.

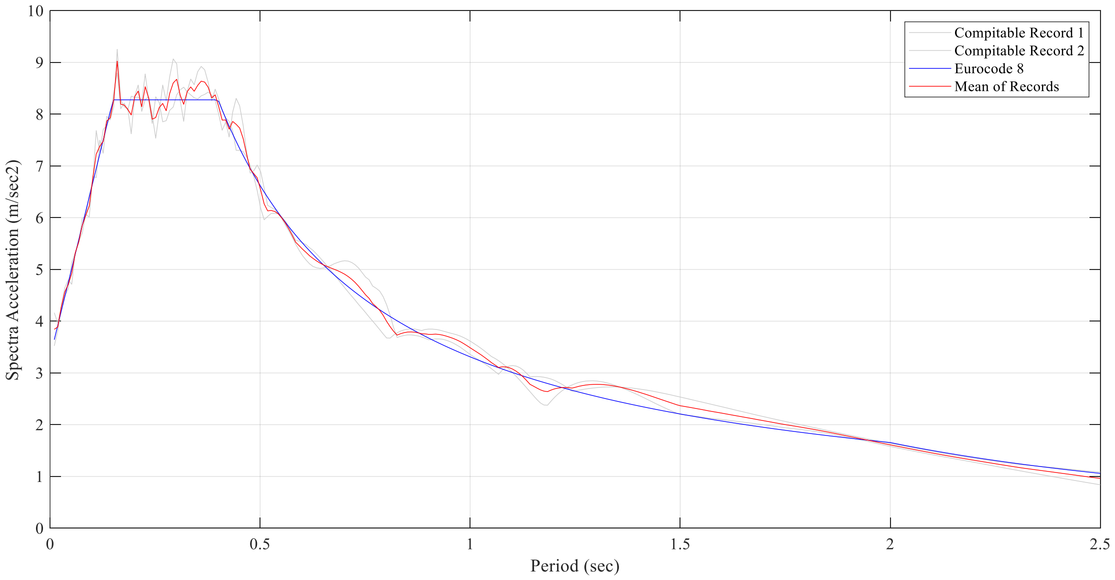

Fig. 3 – Eurocode 8 spectra compared with the scaled ground motion from the 2000 South Iceland Earthquake.

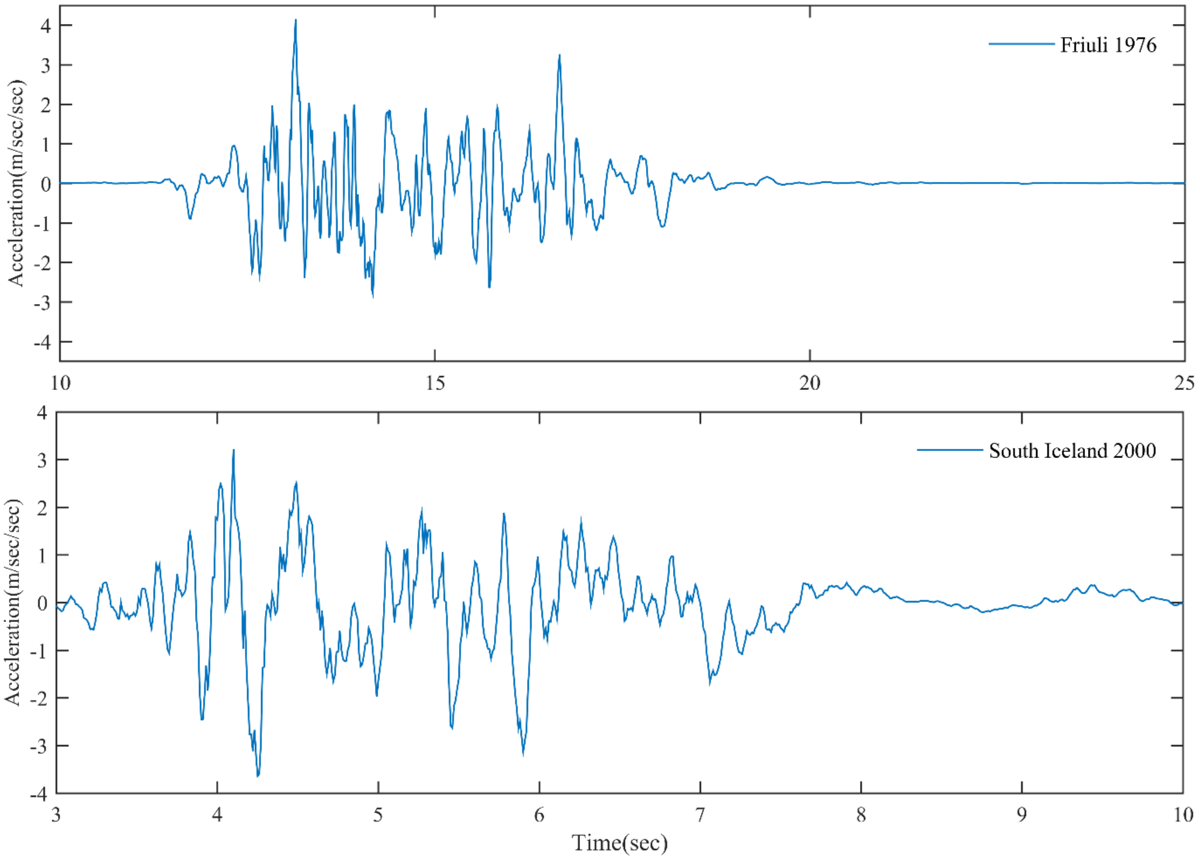

Fig. 4 – Ground motion from Friuli and South Iceland earthquakes scaled and modified to be compatible with the Eurocode 8 spectrum.

The mass of STMD is assumed to be 3% of total mass of the building. Same mass ratio is maintained in MTMDs and d-MTMDs, where the total TMD mass is divided into 6 parts. The stiffnesses of the different TMDs in MTMDs and d-MTMDs are equal. The optimum parameters of STMD and MTMDs are estimated by formula proposed by Sadek et al. [28]. Optimal parameters of d-MTMDs are obtained from a detailed parametric study explained below.

3.1 Parametric study of optimal d-MTMD

The parameters being investigated are the frequency tuning ratio and damping ratio of the TMDs, which are tuned to the frequencies around the fundamental vibration frequency of the building. For each ground motion, response quantities such as root mean square (rms) and peak displacement and acceleration at the top floor are calculated for a wide range of these parameters. Frequency tuning ratio is varied in the range 0.85 to 1.15, and damping ratio is varied in the range of 1% to 20%.

Figure 5 shows the variation of rms and peak acceleration at the top floor of the building for different values of frequency tuning ratio and damping ratio. For controlling rms acceleration, the optimal frequency ratio is around 0.95. At this tuning frequency, the dependence of rms acceleration on TMD damping ratio shows different pattern for the two ground motions considered here. The optimal damping ratio for the South Iceland earthquake ground motion is around 4%, but the response is independent of damping ratio of the TMD. The optimal damping ratio for Friuli earthquake ground motion is around 6%. Unlike the other ground motion, lower damping results in significantly higher rms response in this ground motion.

For controlling peak acceleration at the roof, optimal frequency ratio is more than 1 for both ground motions. When the frequency ratio is more than 1, the peak acceleration caused by the Friuli earthquake ground motion is independent of the TMD damping ratio. However, for the South Iceland earthquake ground motion, optimal damping ratio is around 1-2%. It is however noteworthy that the range of variation in peak acceleration is larger than that in rms acceleration. This indicates that tuning frequency and damping ratio of the TMD have more effect on rms acceleration than peak acceleration. An implication of this observation is that even if the TMDs are not properly tuned, the effect on peak acceleration is not very large. It is also interesting to note that the performance of the TMDs when subjected to the two ground motions are different although the ground motions have similar amplitude and frequency content. This difference is likely due to the different durations of these ground motions. As can be seen from Figure 4, the Friuli ground motion has much longer duration than the South Iceland ground motion. This is an indication that the duration of ground motion plays an important role in the performance of TMDs.

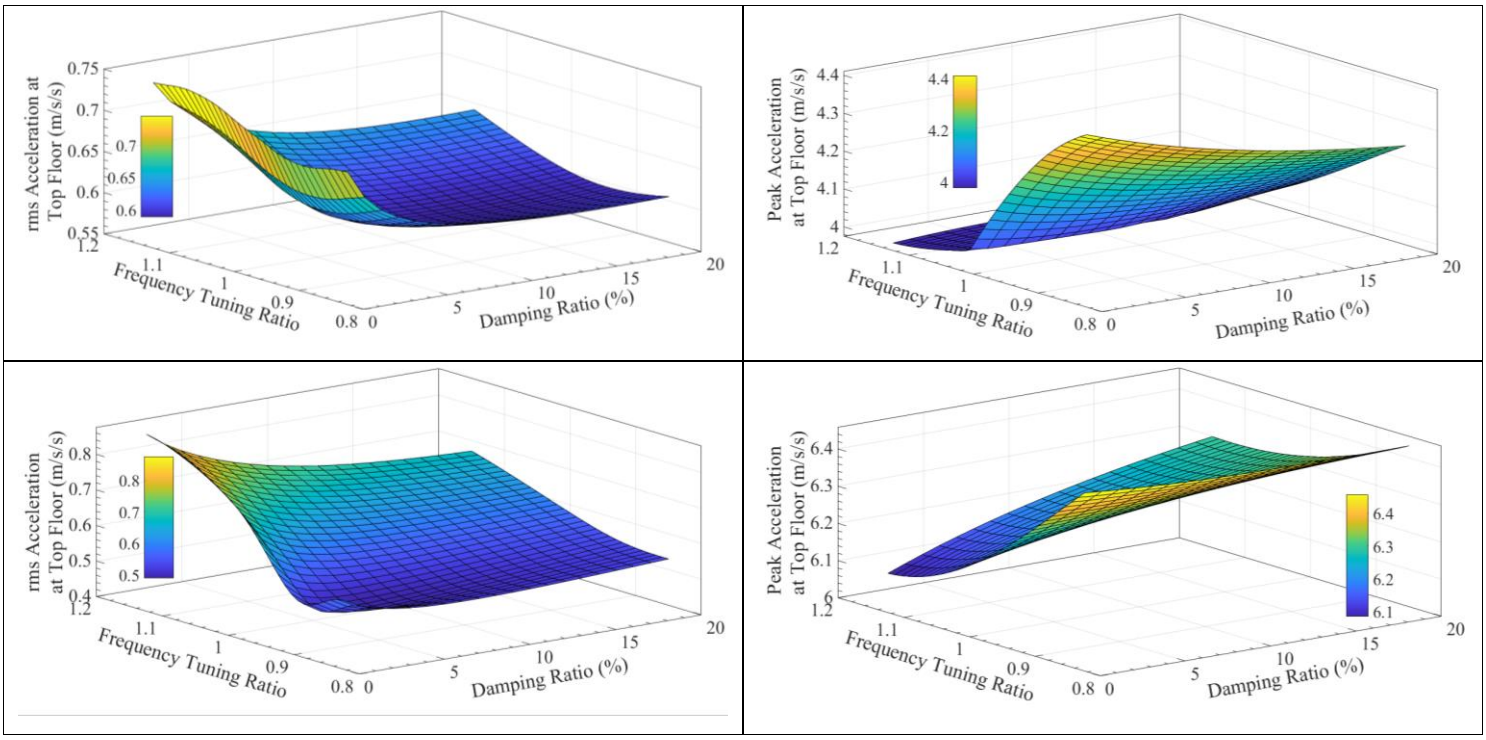

Fig. 5 – Variation of rms and peak acceleration with frequency tuning ratio and damping ratio under the Friuli (top panel) and South Iceland earthquake ground motions.

Figure 6 shows the variation of rms and peak displacement at the top floor of the building for different values of frequency tuning ratio and damping ratio. The optimal solutions for rms acceleration and rms displacement are similar. But the optimal solution for peak displacement is different than that for peak acceleration, and is also different for the two ground motions. For example, the optimal solution for acceleration control during the South Iceland ground motion is the worst solution for peak displacement control. Again the range of peak displacement corresponding to the different TMD parameters is much smaller than the range of rms displacement. Considering the effect of ground motions and the TMD parameters in different response quantities, frequency ratio of 0.89 and damping ratio of 0.05 were selected as optimal parameters.

3.2 Results

Figures 7 and 8 show the displacement and acceleration response of the building with and without TMD schemes. It is observed that the TMD schemes are not very effective in reducing the peak response of the building. The reduction of peak acceleration and displacement at top floor is respectively around 10% and 13% when using an STMD. This reduction marginally increased to 13% and 17% when using MTMDs. The reduction of peak acceleration and displacement at top floor is respectively around 17% and 23% when using d-MTMDs.

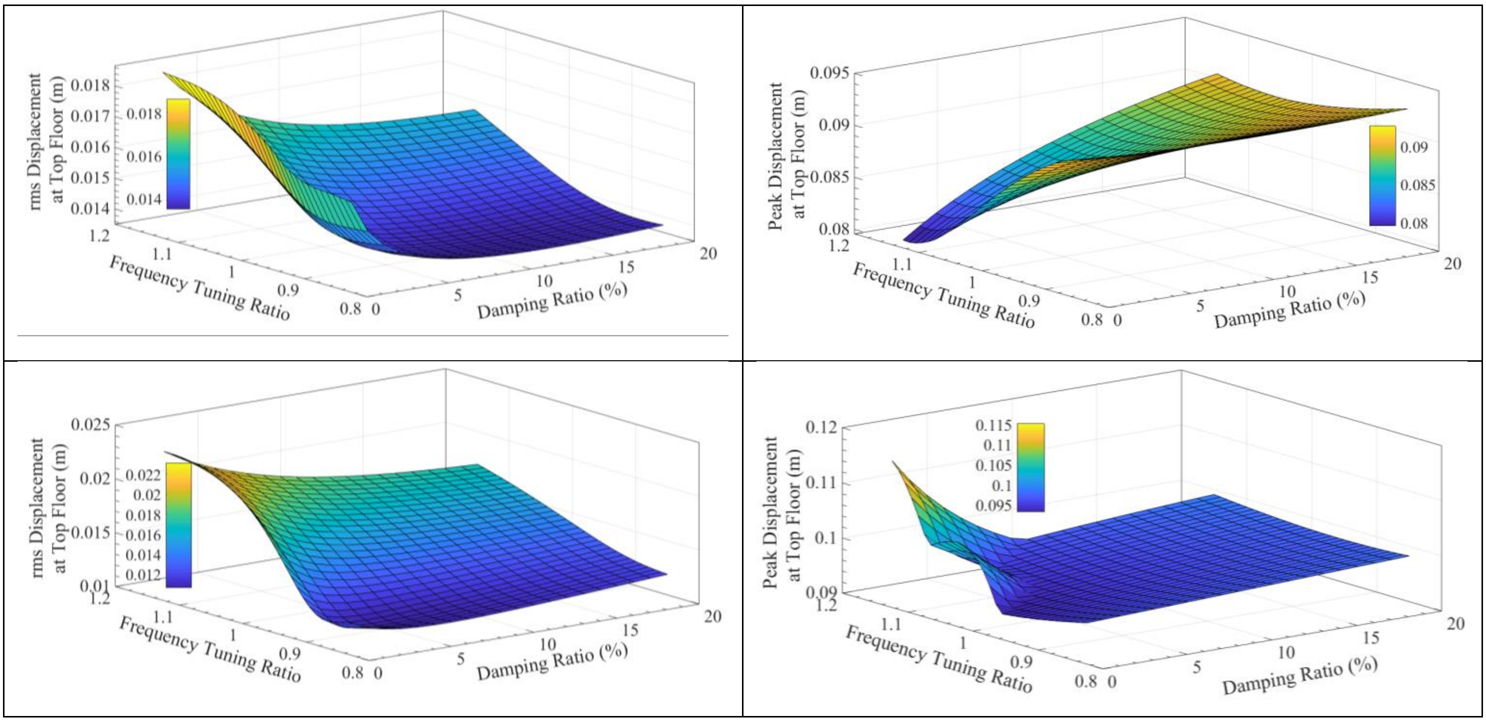

Fig. 6 – Variation of rms and peak displacement with frequency tuning ratio and damping ratio under the Friuli (top panel) and South Iceland earthquake ground motions.

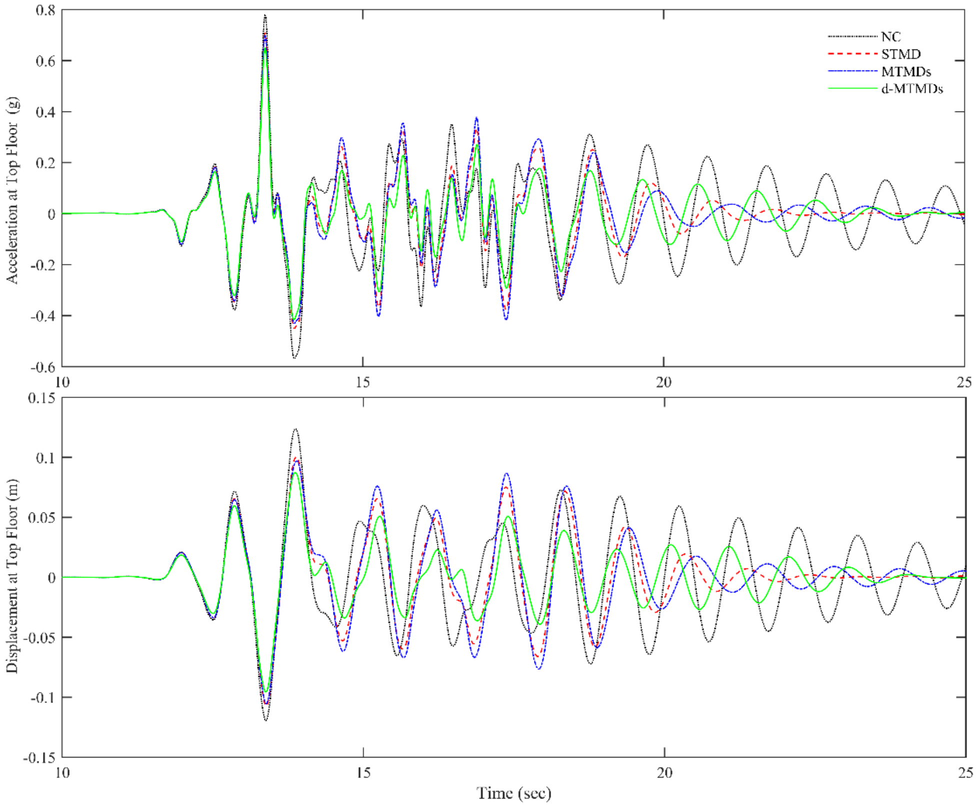

Fig. 7 – Time history response of different schemes under Friuli ground motion.

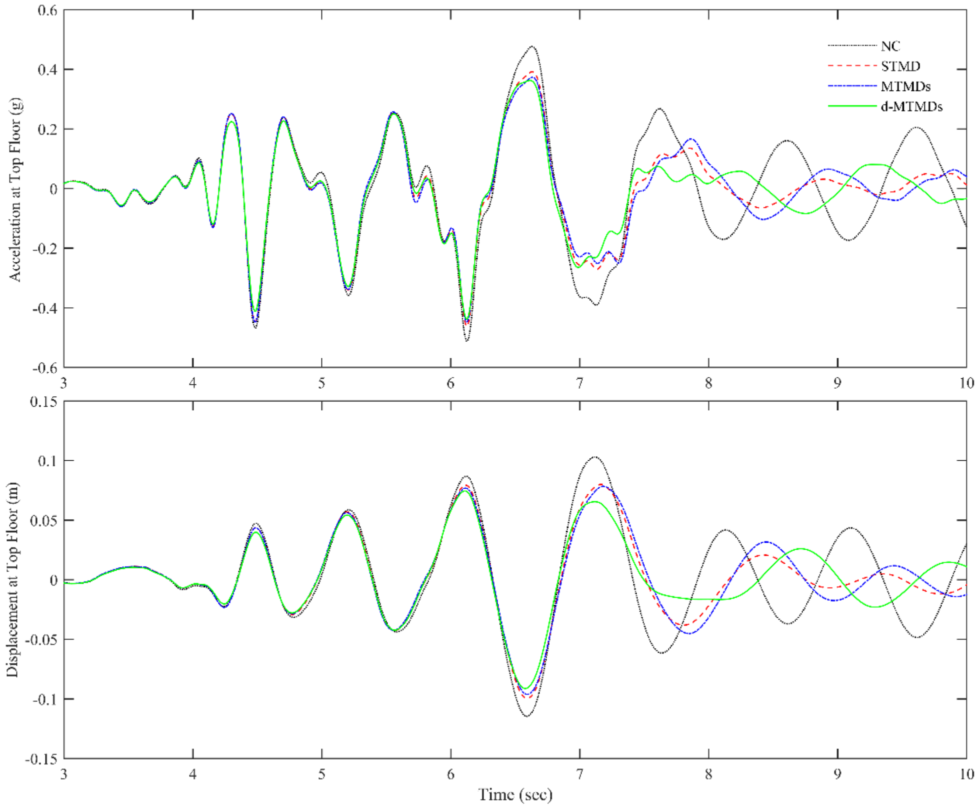

Fig. 8 – Time history response of different schemes under South Iceland earthquake ground motion.

Peak and root mean square (rms) acceleration and displacement of the building with and without TMD schemes along the height of building are shown in Figures 9 and 10. The TMDs are much more effective in controlling rms response than peak response. The MTMDs and d-MTMDs are found to amplify the rms acceleration at the first floor by a small amount. The multiple TMDs provide better control of rms response than single TMDs, but distribution of the TMD mass along the height does not seem to offer additional benefits for this structure.

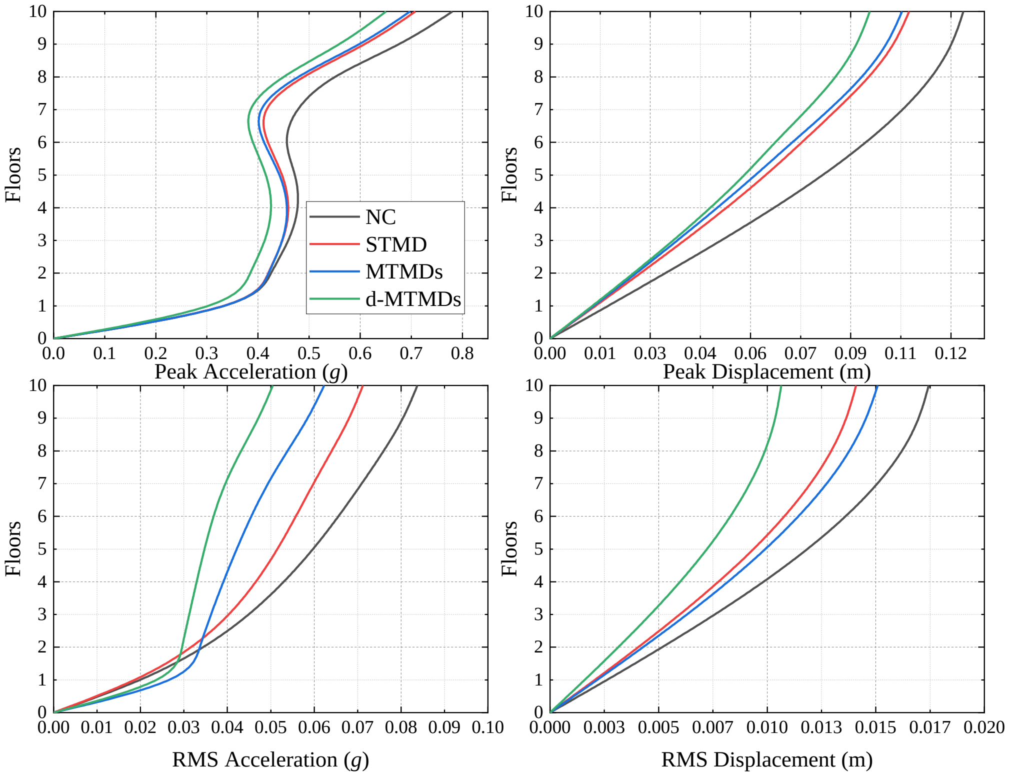

Fig. 9 –Response of different schemes under Friuli ground motion

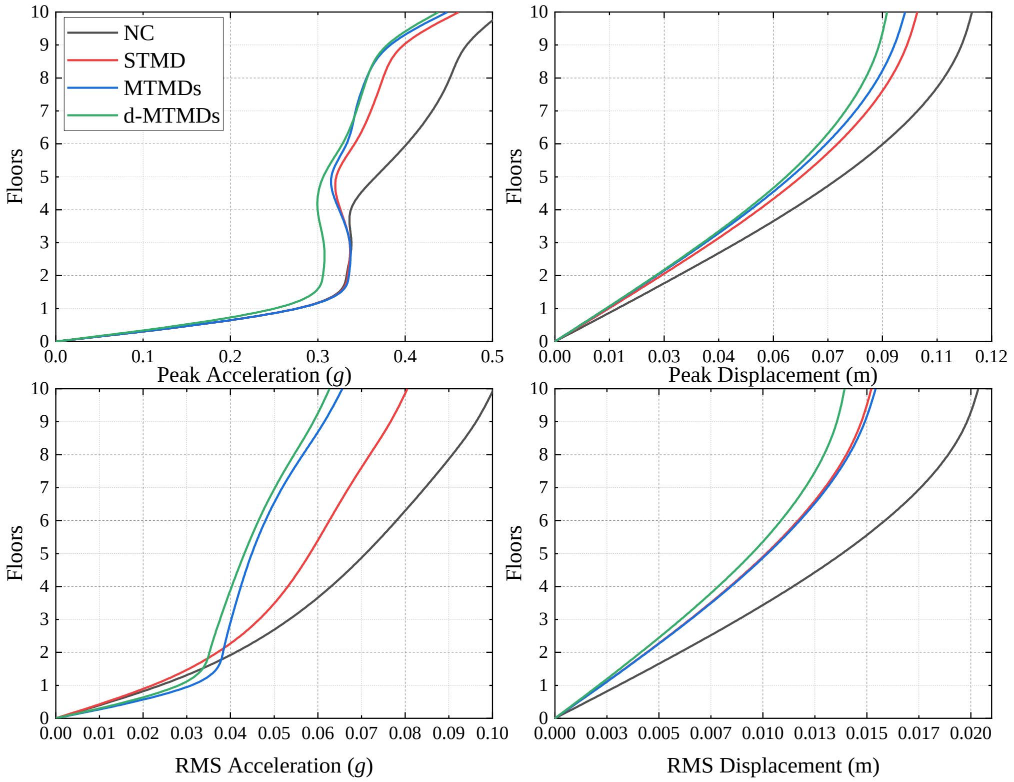

Fig. 10 – Response of different schemes under South Iceland ground motion

4. Conclusions

The study investigates optimal parameters of different schemes of tuned mass damper in controlling seismic response of a 10 storey building. Seismic action is represented by two ground motions scaled to be proportional to the Eurocode 8 response spectra at rock site. The results indicate that the optimal TMD parameters for controlling rms response is like what has been reported in the literature, for example by Sadek [25]. However, these formulations are not optimal to control peak response. The range of reduction that can be achieved in peak response is much smaller than that in rms response. Therefore, the TMDs investigated here are not effective in peak response control but are quite effective in rms response control. For harmonic excitations, rms response control can be an important strategy, but for transient excitations like earthquake ground motions, it might be more relevant to control peak displacement. It is also observed that the optimal parameters of the TMDs depend on the duration of ground shaking. A more detailed study on the effect of ground motion characteristics and formal optimization of TMD parameters as well as their effectiveness in scenario ground motions is felt necessary.

4. Acknowledgements

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5. Copyrights

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