Analysis of benchmark building under DBE earthquakes

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Abstract

The study aims to investigate the analysis of a steel benchmark structure under design bases earthquake (DBE) excitations. Based on defined limit states of the story drift, level of failure is determined for the building subjected to DBE earthquakes. Immediate occupancy (IO), life safety (LS) and collapse prevention (CP) of the building before and after installation of tuned mass damper (TMD) schemes while subjected to the DBE earthquakes is estimated. The TMD schemes are: a single TMD (STMD), multiple TMDs placed at top floor (MTMDs), and MTMDs distributed along the height of the building (d-MTMDs). It is observed that TMD schemes are effective in reducing the response of the building. It is also, seen that the STMD may amplify the response in some of the floors, this would cause damages.

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

1.Introduction

Use of passive tuned mass damper (TMD) is well-established among researchers and engineers. It is also common understanding that multiple TMDs are more effective than a TMD. Bandivadekar and Jangid [1] presented the optimization procedure for the MTMDs to control vibration response of the system under external excitation. The placement of MTMDs was investigated to increase the efficiency of the MTMDs. For example: (i) the effects of installing the MTMDs according to floor acceleration studied by Chen and Wu [2]; (ii) placement of the MTMDs as per mode shapes of the building proposed by Elias and Matsagar [3, 4]. Xiang and Nishitani [5] showed the performance MTMDs for seismic response control of low-rise buildings. Later, Elias et al. [6] investigated the effectiveness of the multi-mode control of chimneys subjected to ground excitations. The placements of the TMDs were considered as per the modal properties of the uncontrolled chimney. They found better performance of the TMDs controlling different modal responses as compared to those controlling only the fundamental modal response. All the studies showed the better performance of MTMDs as compared to placing a STMD. However, structures responding in the elastic domain were considered in these research works. The structural members even in controlled structures can be expected to exceed the elastic limit under large seismic events, such as the 1994 Northridge and the 1995 Kobe earthquakes. Research work related to structures with TMDs responding in the inelastic domain is very limited. Wong and Johnson [7] investigated the ability to use TMDs in improving inelastic structural performance to dissipate the earthquake input energy. They used the sequential procedure based on minimum plastic energy dissipation to determine the proper placements of the TMDs. They reported that the reduction in plastic energy dissipation is quite sensitive to the earthquake vibration characteristics, and TMDs should not be used for structures with weak upper stories. Sgobba and Marano [8] investigated the optimum design of the TMDs for the seismic protection of inelastic structures. They reported that the application of a TMD system reduces the amount of the hysteretic dissipated energy. Later, Wong and Harris [9] investigated the effectiveness of the TMDs to improve the structure's ability to dissipate earthquake input energy using seismic fragility curves. They reported that the TMD can enhance the structure's ability to dissipate energy at low levels of earthquake shaking. They also reported that TMD would be less effective during moderate to strong earthquakes, which can cause a significant period shift associated with major structural damage. In addition, they suggested that an extremely sizable TMD is not effective in reducing damage of a structure because of the 'de-tuning' effect. Elias and Matsagar [10] showed that the d-MTMDs were more effective in reducing the damages of buildings as compared to STMD and MTMDs. Therefore, to extend the study [10], it is important to check the floors that may get damages due to installation of TMD schemes. This will be presented in the current study.

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, c) installed with MTMDs, and d) installed with d-MTMDs. The detail of the building and design parameters of TMD schemes are given by Elias and Matsagar [10]. Matrices and general formulations are given by Elias and Matsagar [10]. 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_i is the displacement of i^{th} TMD.

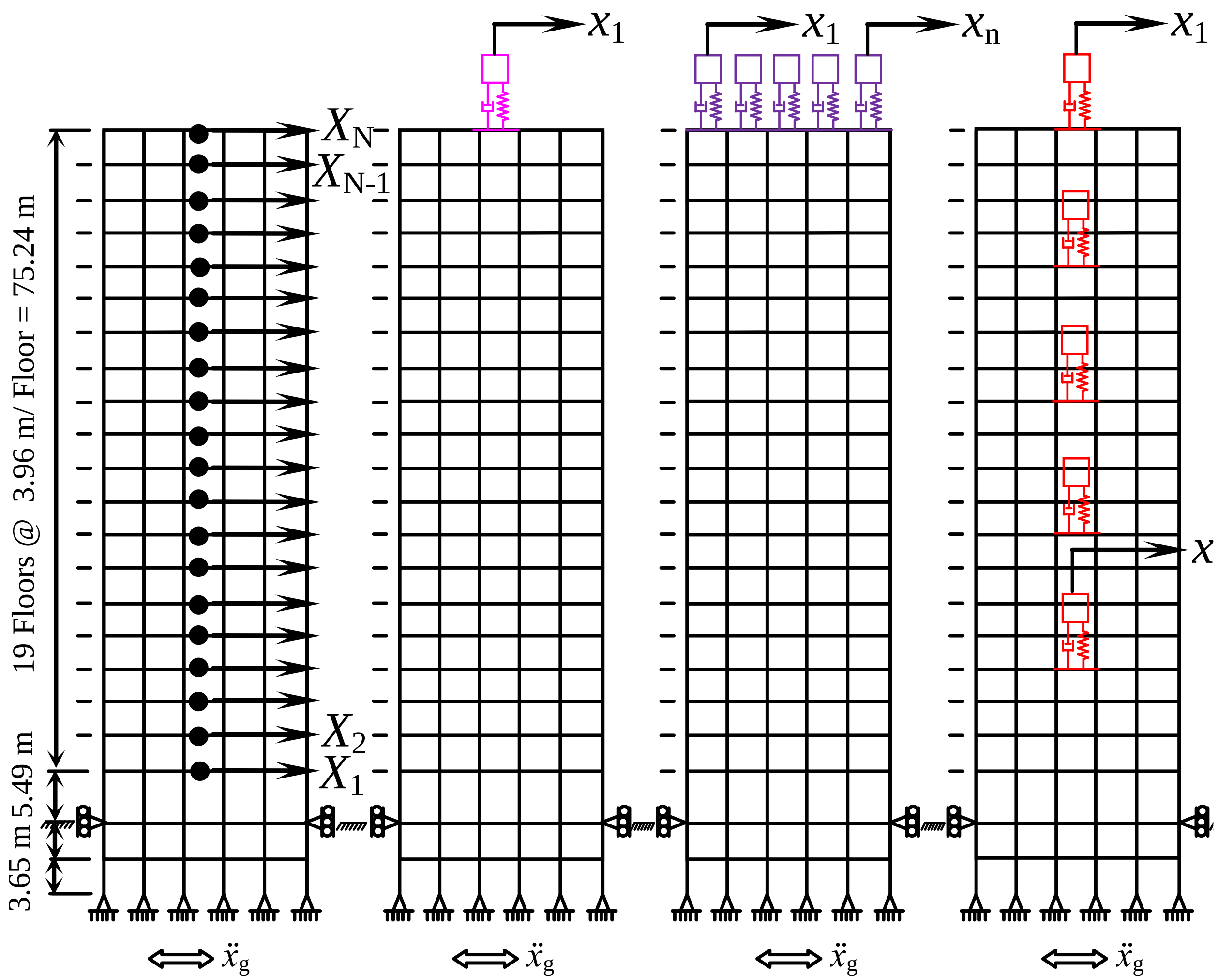

Fig. 1 – Mathematical model of *N*-story (a) NC, (b) STMD at top floor, (c) MTMDs at top floor and (d) d-MTMDs at different floors

3. Numerical Study

In this study a 20-story steel building is taken from a study by Elias and Matsagar [10]. A detailed literature survey by Elias and Matsagar [11]. Design bases earthquakes are taken from the study presented by Elias and Matsagar [10] and Stanikzai et al. [12]. The mass of STMD is assumed to be 5% of total mass of the building. Same mass ratio is maintained in MTMDs and d-MTMDs, where the total TMD mass is divided into 5 parts. The mass 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. [13].

3.1 Results and discussions

Figures 2 through 5 show the inter-story drift (IDR) of the from first to top floor of the steel benchmark building. Also, figures contain the comparison of different TMD schemes in seismic response control of building. The Federal Emergency Management Agency [14] has provided the guidelines for structural performance levels. These performance levels must be checked for the steel structures under: (i) immediate occupancy, (ii) life safety and (iii) collapse prevention stages. As per the FEMA 273 [14] for steel framed structure, the drift of 0.7%, 2.5% and 5%, respectively, are valid for the immediate occupancy (IO), life safety (LS) and collapse prevention (CP) stages.

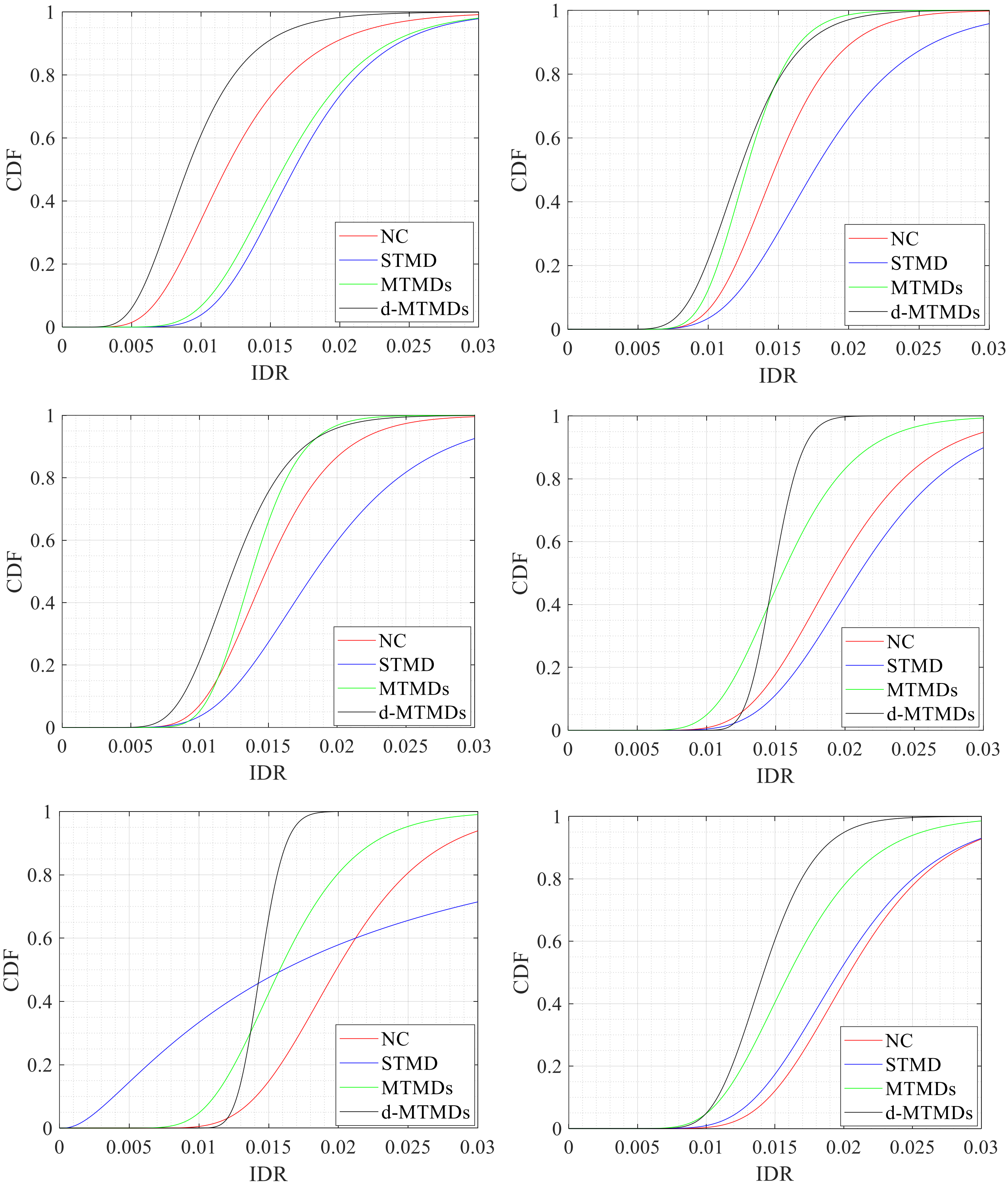

Fig. 2 – Inter-story drift of floors 1-6 of *N*-story building as NC, STMD, MTMDs at top floor and d-MTMDs at different floors

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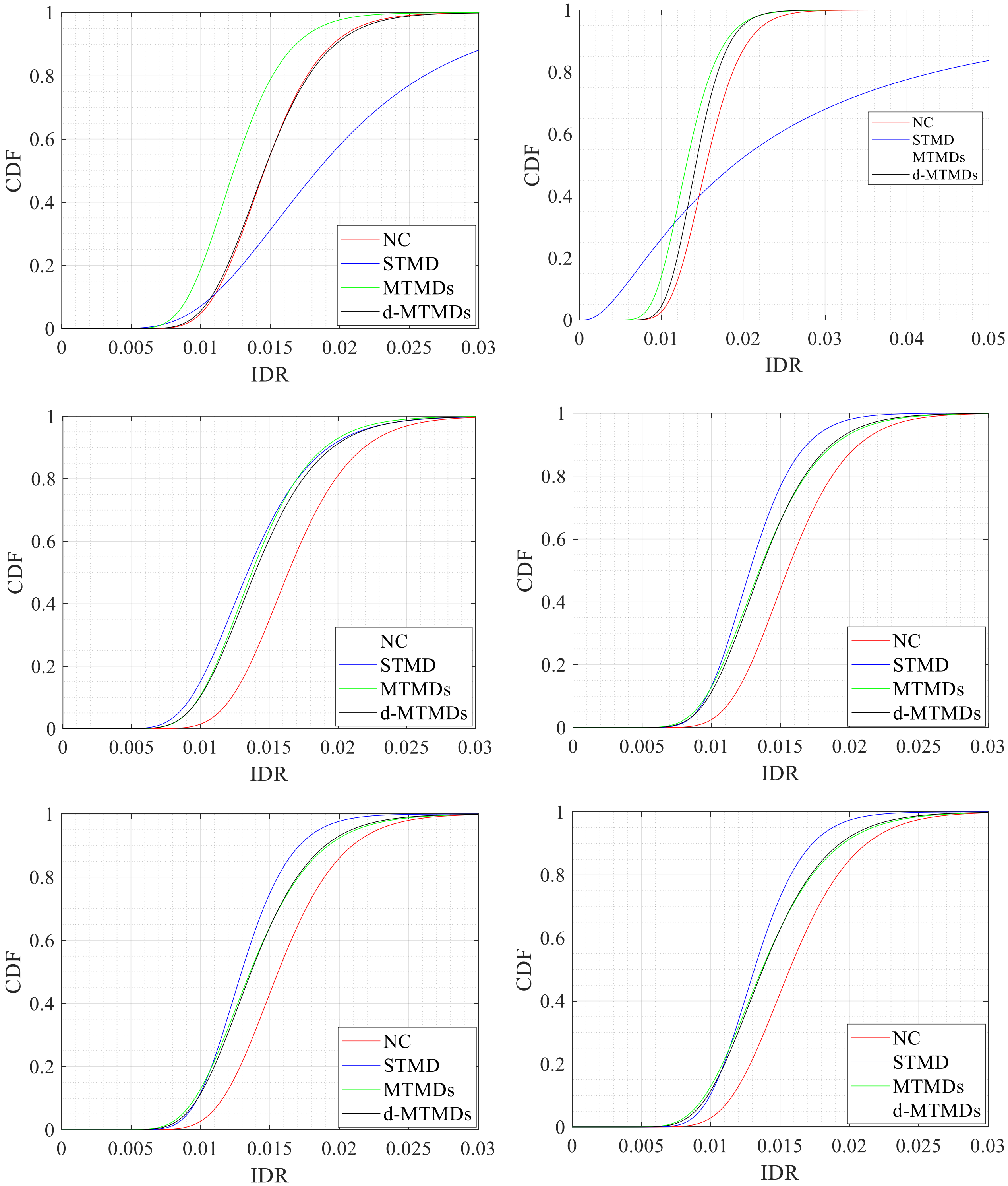

Fig. 3 – Inter-story drift of floors 7-12 of *N*-story building as NC, STMD, MTMDs at top floor and d-MTMDs at different floors

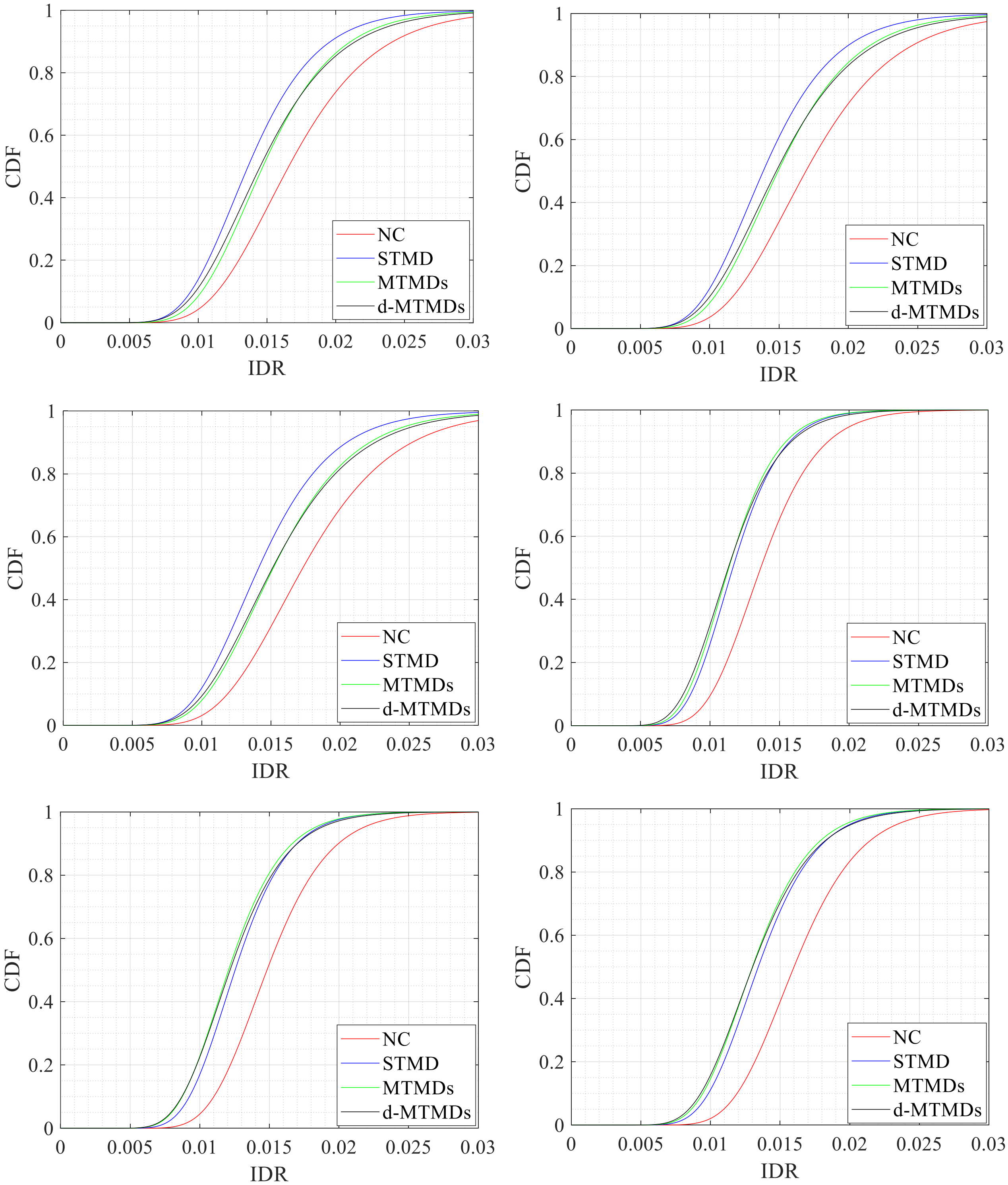

Fig. 4 – Inter-story drift of floors 13-18 of *N*-story building as NC, STMD, MTMDs at top floor and d-MTMDs at different floors

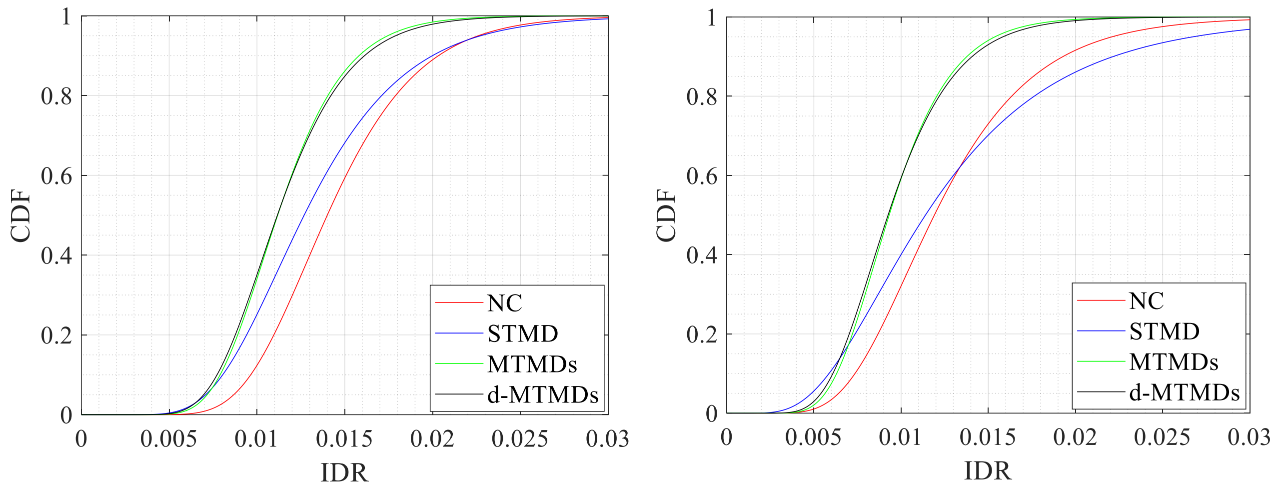

Fig. 5 – Inter-story drift of floors 1-6 of *N*-story building as NC, STMD, MTMDs at top floor and d-MTMDs at different floors

Figure 2 shows the IDR of first six floors for the NC and TMD schemes under DBE earthquakes. It is observed that the IDR of first floor increased by installation of STMD and MTMDs. In addition, it seen that there is 80% probability that first floor may go to IO damage level. Off course this issue is exist in all floors.

Table 1Damage statement of dofferent floors

PGA	NC			STMD			MTMDs			d-MTMDs		
PGA	IO	LS	CP	IO	LS	CP	IO	LS	CP	IO	LS	CP
0.23	19	0	0	20	3	0	20	0	0	19	0	0
0.3	20	9	0	20	2	0	20	3	0	19	3	0
0.36	20	0	0	20	5	0	20	0	0	19	0	0
0.39	20	0	0	18	2	0	20	0	0	19	0	0
0.42	19	3	0	19	4	0	20	0	0	20	0	0
0.43	19	0	0	20	4	0	19	0	0	18	0	0
0.46	20	0	0	18	2	0	20	0	0	20	0	0
0.49	20	0	0	20	0	0	20	0	0	19	0	0
0.52	20	3	0	20	5	0	20	1	0	20	0	0
0.53	20	0	0	20	2	0	20	0	0	20	0	0
0.57	20	0	0	20	3	0	20	0	0	20	0	0
0.58	20	0	0	20	4	0	20	1	0	20	1	0
0.66	20	1	0	20	3	0	20	1	0	20	0	0
0.67	20	0	0	20	3	0	20	0	0	19	0	0
0.68	20	0	0	18	0	0	20	0	0	20	0	0
0.68	20	0	0	20	5	0	20	0	0	20	0	0
0.82	20	2	0	20	2	0	20	0	0	20	0	0
0.97	19	0	0	19	0	0	19	0	0	19	0	0
0.99	20	0	0	20	3	0	20	0	0	20	0	0
1.02	20	0	0	19	0	0	19	0	0	18	0	0

Further, it is noticed that adding single huge mass may amplify the response and creates damages in the lower floors. Up to 4o% probability is exist that due to installation of STMD, the building would experience LS damage state, which is quite harmful for the safety of occupants. This selected building with and without TMDs will not reach CP stage while subjected to DBE earthquakes. Summary of the results are shown in Table 1, that confirms that the STMD is increasing with its huge mass. Earthquakes are sorted based on their peak ground acceleration (PGA), all the schemes are shown with number floors that can cross the limit states. In most of cases STMD is showing adverse effect while MTMDs and d-MTMDs are generally, effective in response control.

4. Conclusions

The study investigates the performance different schemes of tuned mass damper in controlling seismic response of a 20-story steel building. Seismic action is represented by DBE ground motions. The results indicate that the Single tuned mass damper may amplify the inter-story drift (IDR). Therefore, the huge STMD investigated here are is not effective in IDR control of lower floors but is effective in response control upper floors. It is also observed that the MTMDs and d-MTMDs are generally showing improved performance as compared to the STMD. 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

6. References

[1] Bandivadekar, T. P., and Jangid, R. S. (2013) “Optimization of multiple tuned mass dampers for vibration control of system under external excitation”, JVC/Journal of Vibration and Control, 19(12), 1854-1871.

[2] Chen, G., and Wu, J. (2001) “Optimal placement of multiple tuned mass dampers for seismic structures”, Journal of Structural Engineering, ASCE, 127(9), 1054-1062.

[3] Elias, S., and Matsagar, V. (2014a) “Wind response control of a 76-storey benchmark building installed with distributed multiple tuned mass dampers”, Journal of Wind and Engineering, 11(2), 37-49.

[4] Elias, S., and Matsagar, V. (2014b) “Distributed multiple tuned mass dampers for wind vibration response control of high-rise building”, Journal of Engineering, http://www.hindawi.com/journals/je/aip/198719/.

[5] Xiang, P., and Nishitani, A. (2014) “Seismic vibration control of building structures with multiple tuned mass damper floors integrated”, Earthquake Engineering and Structural Dynamics, 43(6), 909-925.

[6] Elias, S., Matsagar, V., and Datta, T. K. (2016) “Effectiveness of distributed tuned mass dampers for multi-mode control of chimney under earthquakes”, Engineering Structures, 124, 1-16.

[7] Wong, K., and Johnson, J. (2009) “Seismic energy dissipation of inelastic structures with multiple tuned mass dampers”, Journal of Engineering Mechanics, ASCE, 135(4), 265-275.

[8] Sgobba, S., and Marano, G. C. (2010) “Optimum design of linear tuned mass dampers for structures with non-linear behavior”, Mechanical Systems and Signal Processing, 24(6), 1739-1755.

[9] Wong, K. K. F., and Harris, J. L. (2012) “Seismic damage and fragility analysis of structures with tuned mass dampers based on plastic energy”, Structural Design Tall and Special Buildings, 21(4), 296-310.

[10] 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.

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

[12] Stanikzai, M.H.; Elias, S.; Rupakhety, R. Seismic Response Mitigation of Base-Isolated Buildings. Appl. Sci. 2020, 10, 1230.

[13] Sadek, F., Mohraz, B., Taylor, A. W., & Chung, R. M. (1997). A method of estimating the parameters of tuned mass dampers for seismic applications. Earthquake Engineering & Structural Dynamics, 26(6), 617-635.

[14] FEMA 273 (1997) "NEHRP guidelines for the seismic rehabilitation of buildings", Federal Emergency Management Agency, Washington, D.C., USA.

