Effect of Tuned Mass Damper as a Soft Storey on Multi-Storeyed Framed Structures

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Abstract *- The seismic waves caused by earthquake makes the multi-storeyed structure to sway and oscillate in several directions. To improve the seismic performance and minimize the damage due to earthquake on the structures, passive vibration control methods are used, here we will use a Tuned Mass Damper(TMD) as a soft storey placing at the highest story of a multi-storeyed framed structure. By adopting this method, we will avoid the wastage of building space which we would have liked to supply for other sorts of tuned mass damping devices and also, we will use the top storey as utility space. Analysis was be done on multi-storeyed framed structures having plan eccentricities with and without TMD. TMDs with different mass ratios of 2%, 4% and 6% are used for analysis. The results are then compared to find the optimum mass ratio which provide better seismic performance. ETABS software is used for the analysis of the structure.*

Key Words: **Tuned mass dampers(TMD), Mass ratio, Seismic vibration control, Soft storey, Non-Linear Time History Analysis, Storey Displacement, Storey Drift**

1. INTRODUCTION

The need for construction of taller buildings is increasing day by day. These structures are flexible and constructed as light as possible and which have low value of damping. As a result, these structures will be be subjected to vibrations of larger amplitudes of seismic excitations. This vibration creates problem to serviceability requirements of the structure and also reduce structural integrity leading to possible failures. Several techniques are now in use to scale back earthquake induced structural vibration. The structural vibrations produced by earthquake can be controlled by various means, such as modifying rigidities, masses, damping, or shape, and by providing passive or active counter forces. Tuned mass dampers are widely used to control structural vibration during seismic excitation.

In this paper, tuned mass damper in the form of a soft storey is applied on multi-storeyed frames with plan eccentricities. Frames with and without soft storey is modelled and analysed. The parameters used to evaluate the seismic performance of frames are storey displacement and storey drift. Storey displacement is defined as the displacement of a storey with respect to the base of a structure. Story drift is the difference of displacements between two consecutive stories divided by the height of that story. Since the trend of constructing tall buildings is increasing, the significance of finding cost effective structural forms are very important.

In this paper, three different multi-storeyed frames are analysed under time history analysis with same frame properties. The analytical study is carried out by using ETABS 2015.

1.1 Tuned Mass Damper

Tuned mass damper is a passive control device. The TMD concept was first applied by Frahm in 1909, to reduce the rolling motion of ships as well as ship hull vibrations. A tuned mass damper is simply a mass, spring, damper system. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited, the damper will resonate out of phase with the structural motion. Energy is dissipated by the damper inertia force acting on the structure. The TMD is installed in the top of the building and can reduce the displacement of the building.

1.2 Soft Storey

When sudden change of stiffness takes place along the building height, the storey of which the drastic reduction of stiff-ness is observed is known as soft storey. A Soft Storey is one in which the lateral stiffness is less than 70 percent of that in the store immediately above/below or less than 80 percent of the average lateral stiffness of the three storeys immediately above or below.

1.3 Scope and Objective of the Study

The work is limited to Modelling and analysis of multi-storeyed frames with plan eccentricities.

The main objective of the study are as follows:

- To investigate the performance of T shape building with and without TMD.
- To investigate the performance of H shape building with and without TMD.
- To investigate the performance of Setback building with and without TMD.

2. MODELLING AND ANALYSIS OF FRAMES

Multi-storeyed frames with plan eccentricities are developed for modelling and analysis. The basic building plan and properties were adopted from [9]. A 13-storey rectangular building were remodelled as T shape, H shape and Setback building frame. After remodelling a tuned mass damper as a soft storey is placed as a 14th storey. Soft storey with different mass ratios of 2%, 4% and 6% is considered for studying seismic performance of the frames. Time history analysis (El Centro-1940 earthquake data) were done on frames with and without soft storey. The maximum storey displacement and maximum storey drift are the parameters considered for analysing the seismic performance of the frames.

2.1 Specifications

The basic building plan and properties were adopted from[9].

Beam size	= 300 x 600
Column size	= 300 x 900
Live Load on slab	= 3.5 kN/m^2
Soft storey height	= 2m

2.2 Modelling of Frames

Model 1: T Shape frame with and without TMD
Model 2: H Shape frame with and without TMD
Model 3: Setback type frame with and without TMD

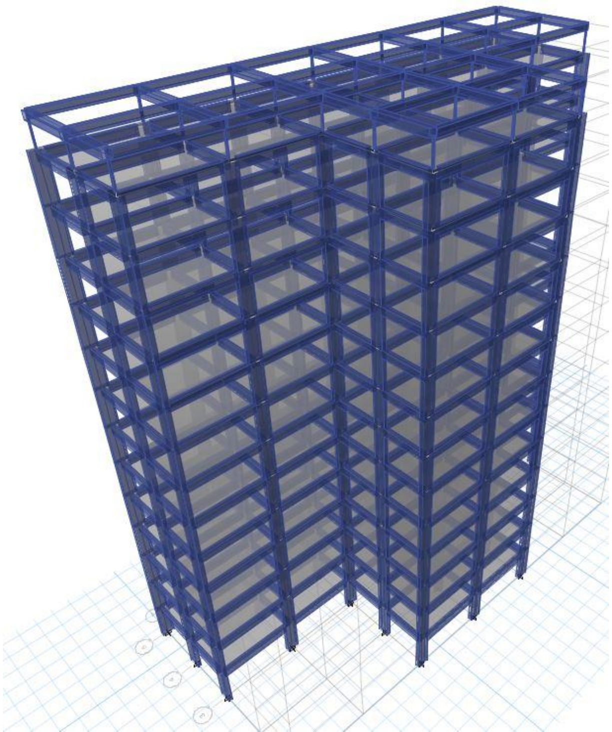

Fig -1: 3D view of T shape frame with TMD

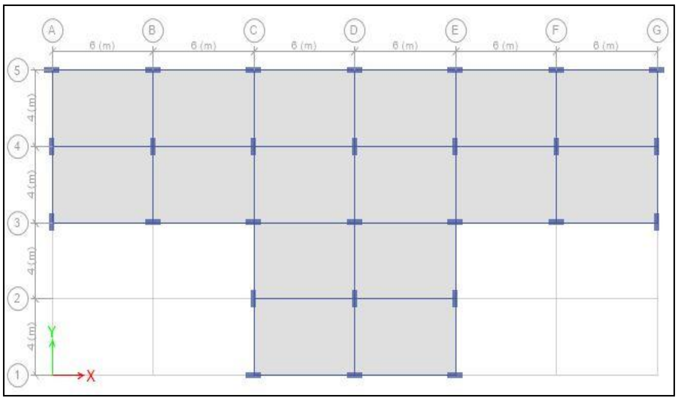

Fig -2: Plan of T shape frame

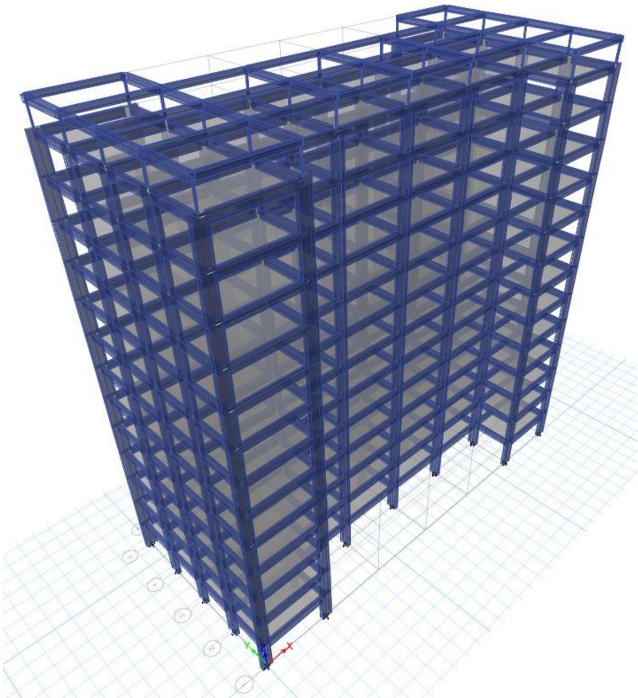

Fig -3: 3D view of H shape frame with TMD

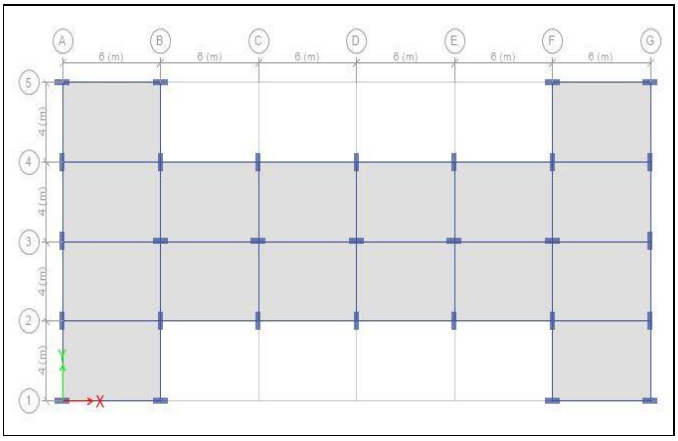

Fig -4: Plan of H shape frame

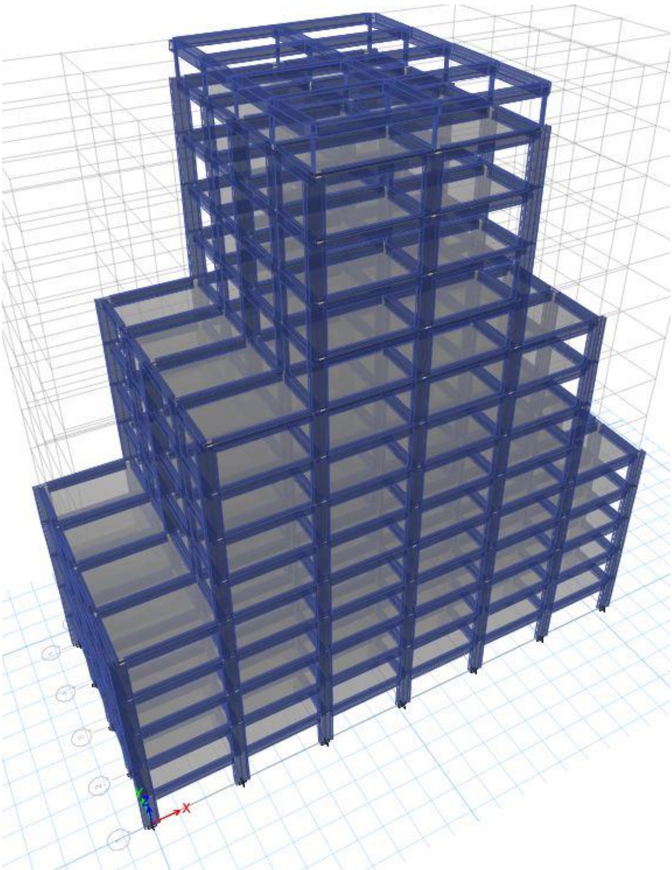

Fig -5: 3D view of Setback frame with TMD

2.3 Analysis

A total of nine models and nine analysis were done here. Nonlinear time history analysis was done on each model. The analysis was done using ETABS 2015 software. El Centro(1940) earthquake data was used for the analysis which was obtained from PEER NGA database. The frames were first modelled without TMD and analysed using time history analysis. Then, the same frame was analysed with TMDs with various mass ratios. Then comparison between the seismic behaviour of frames with and without TMD was done.

3. RESULTS AND DISCUSSIONS

The maximum storey displacement and maximum storey drift for each model are shown in Table 1 to Table 6 and the comparison chart showing the effects of TMDs with respective mass ratios are shown in chart 1 to chart 6. Comparison of multi-storeyed frames with and without TMDs are done.

Table -1: Maximum Story Displacement of T Shape Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	88.1	76.4	67.4	63.3
12	85.4	74.7	66.3	61.7
11	81.3	71.8	64.1	59.1
10	76.1	67.7	60.5	55.4
9	69.9	62.3	55.8	50.7
8	63	56	51.7	47.4
7	55.4	49.1	47.5	43.6
6	47.2	42.8	42.3	38.9
5	38.4	36.6	36	33.3
4	29.4	29.3	28.9	26.7
3	20.9	21.3	20.9	19.4
2	12.5	12.8	12.6	11.7
1	4.6	4.7	4.7	4.3
0	0	0	0	0

Table 1 shows the maximum storey displacement of T shape frame. From Table 1, it is clear that the maximum storey displacement occurred at 13th storey. Maximum storey displacement without TMD is 88.1 mm. Maximum storey displacement with 2% TMD is 76.4 mm, 4% TMD is 67.4 mm and 6% TMD is 63.3 mm. From the results, it is clear that the seismic performance of T shape frame in terms of maximum story displacement is improved very well by introducing TMD. The percentage reduction in maximum storey displacement is 28.149%.

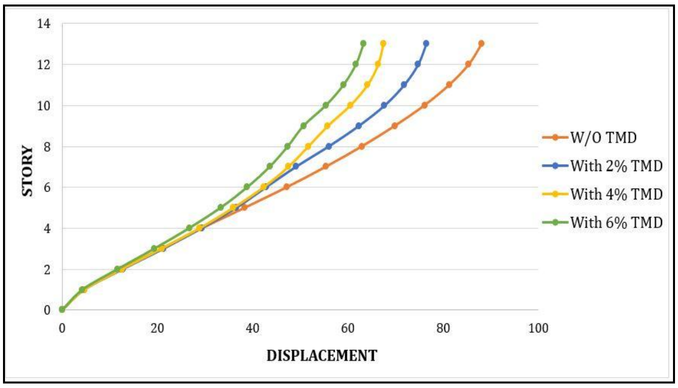

Chart -1: Graph Showing Maximum Story Displacement of T Shape Frame with & Without TMD

Table -2: Maximum Story Drift of T Shape Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	0.000927	0.000674	0.00069	0.00067
12	0.001377	0.001043	0.00106	0.00104
11	0.001756	0.001397	0.0014	0.00136
10	0.002061	0.001781	0.00161	0.00157
9	0.002305	0.002092	0.00187	0.00178
8	0.002527	0.002325	0.0021	0.00195
7	0.002738	0.002482	0.00224	0.00206
6	0.002912	0.002572	0.00232	0.00212
5	0.003006	0.002607	0.00239	0.00219
4	0.002995	0.002682	0.00264	0.00244
3	0.002866	0.002836	0.00279	0.00258
2	0.00265	0.0027	0.00265	0.00246
1	0.001529	0.001562	0.00156	0.00144
0	0	0	0	0

From Table 2, it is clear that the maximum storey drift occurred at 5th storey. Maximum storey drift without TMD is 0.003006. Maximum storey drift with 2% TMD is 0.002607, 4% TMD is 0.00239 and 6% TMD is 0.00219. From the results, it is clear that the seismic performance of T shape frame in terms of maximum story drift is improved by introducing TMD. The percentage reduction in maximum storey drift is 27.145%.

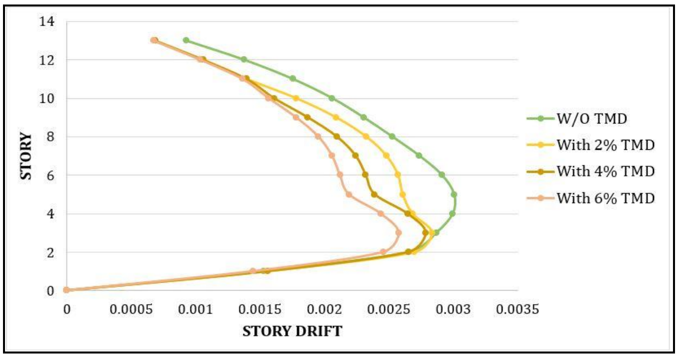

Chart -2: Graph Showing Maximum Story Drift of T Shape Frame with & Without TMD

Table -3: Maximum Story Displacement of H Shape Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	87.7	66.8	48.8	39.8
12	86.4	66.2	49	39.1
11	84.7	65.2	49.1	38
10	82.2	63.6	48.6	37.8
9	78.9	61.2	47.5	37.7
8	74.3	57.8	45.5	36.7
7	68	53.3	42.4	34.8
6	60	47.6	38.3	31.8
5	50.4	40.7	33.1	27.7
4	39.5	32.7	26.7	22.6
3	27.9	23.8	19.5	16.6
2	16.4	14.3	11.8	10.1
1	6	5.4	4.4	3.8
0	0	0	0	0

The Maximum storey displacement occurred at 13th storey without TMD is 87.7 mm. Maximum storey displacement with 2% TMD is 66.8 mm, 4% TMD is 68.8 mm and 6% TMD is 39.8 mm. The percentage reduction in maximum storey displacement is 54.618%.

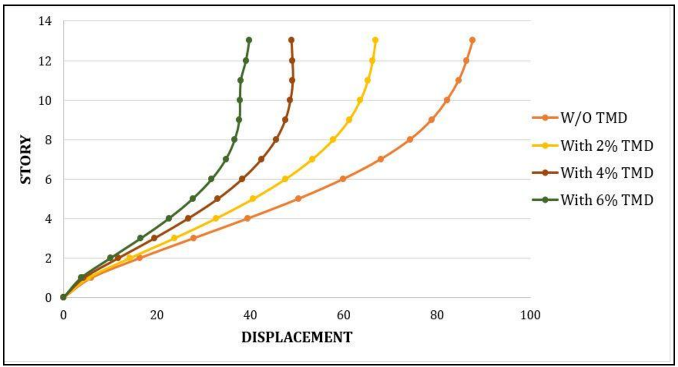

Chart -3: Graph Showing Maximum Story Displacement of H Shape Frame with & Without TMD

Table -4: Maximum Story Drift of H Shape Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	0.000988	0.000602	0.000362	0.00037
12	0.001431	0.000931	0.000628	0.000642
11	0.001771	0.001241	0.000875	0.000896
10	0.001931	0.001456	0.001029	0.001056
9	0.001933	0.00155	0.001066	0.001097
8	0.002148	0.001523	0.001261	0.001019
7	0.002668	0.001895	0.001458	0.00118
6	0.00322	0.002297	0.001751	0.001361
5	0.003633	0.002672	0.002105	0.001706
4	0.003848	0.002981	0.0024	0.001995
3	0.003845	0.00316	0.00258	0.00218
2	0.003495	0.003018	0.002485	0.002119
1	0.002009	0.001786	0.00148	0.001264
0	0	0	0	0

The Maximum storey drift occurred at 4th storey without TMD is 0.003848. Maximum storey drift with 2% TMD is 0.002981, 4% TMD is 0.0024 and 6% TMD is 0.001995. The percentage reduction in maximum storey displacement is 48.154%.

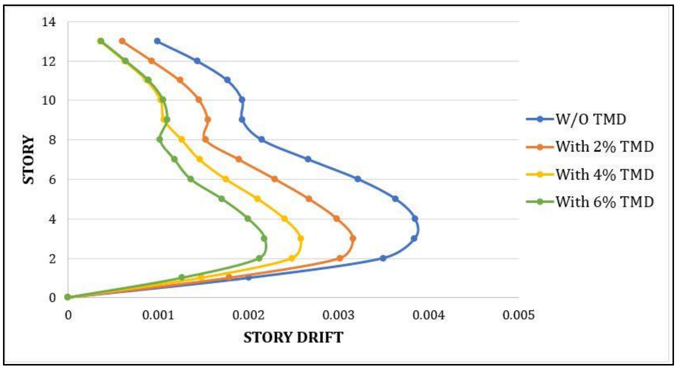

Chart -4: Graph Showing Maximum Story Drift of H Shape Frame with & Without TMD

Table -5: Maximum Story Displacement of Setback Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	150.1	120.4	89.8	70.1
12	145.8	117.7	88.1	69.2
11	139	113.1	84.9	67.1
10	130	106.4	80.1	63.4
9	120	98.5	74.1	58.7
8	109.9	89.9	67.6	53.2
7	97.4	79.2	59.4	46.2
6	82.4	66.7	49.8	38.6
5	66.8	54	40	30.9
4	52.3	42.4	31.3	24
3	37.1	30.3	22.2	17
2	21.9	18.1	13.2	10.1
1	8.1	6.7	4.9	3.7
0	0	0	0	0

The Maximum storey displacement occurred at 13th storey without TMD is 150.1 mm. Maximum storey displacement with 2% TMD is 120.4 mm, 4% TMD is 89.8 mm and 6% TMD is 70.1 mm. The percentage reduction in maximum storey displacement is 53.298%.

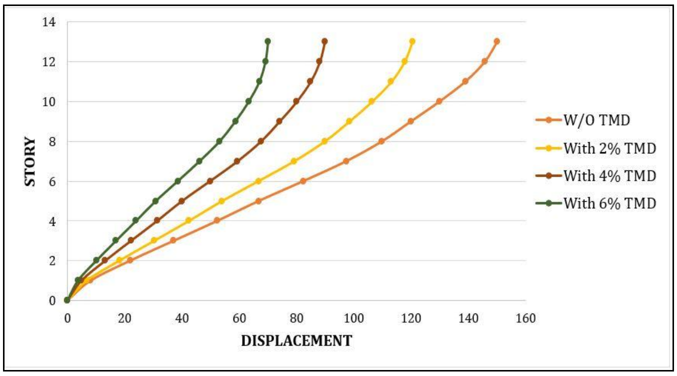

Chart -5: Graph Showing Maximum Story Displacement of Setback Frame with & Without TMD

Table -6: Maximum Story Drift of Setback Frame with & Without TMD

Storey	Without TMD	2% TMD	4% TMD	6% TMD
13	0.00163	0.001412	0.001248	0.001012
12	0.002397	0.002173	0.001984	0.001714
11	0.003009	0.002744	0.002544	0.002264
10	0.003331	0.002687	0.002506	0.002257
9	0.003377	0.002862	0.00227	0.001833
8	0.004193	0.003566	0.002753	0.002318
7	0.004986	0.004161	0.003206	0.002688
6	0.005229	0.004257	0.003263	0.002687
5	0.004877	0.003884	0.00294	0.002339
4	0.00507	0.004033	0.003012	0.002343
3	0.005056	0.004081	0.003009	0.002316
2	0.004633	0.003812	0.002786	0.002126
1	0.002687	0.00224	0.001629	0.001237
0	0	0	0	0

The Maximum storey drift occurred at 6th storey without TMD is 0.005229. Maximum storey drift with 2% TMD is 0.004257, 4% TMD is 0.003263 and 6% TMD is 0.002687. The percentage reduction in maximum storey displacement is 48.613%.

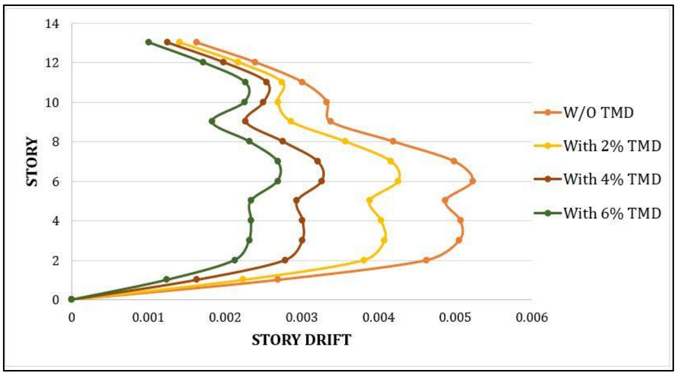

Chart -6: Graph Showing Maximum Story Drift of Setback Frame with & Without TMD

4. CONCLUSIONS

In this paper, three different multi-storeyed frames with plan eccentricities are considered. Storey displacement and storey drift are parameters considered for analyzing the seismic performance of the frames.

- Maximum Storey displacement & Maximum Storey drift is greatly reduced by introducing TMD as a soft story at the top floor
- For T shape frame, TMD with 6% mass ratio is found to have better storey displacement and storey drift control. Percentage reduction in maximum storey displacement is 28.149% and percentage reduction in maximum storey drift is 27.145%.
- For H shape frame, TMD with 6% mass ratio is found to have better storey displacement and storey drift control. Percentage reduction in maximum storey displacement is 54.618% and percentage reduction in maximum storey drift is 48.154%.
- For Setback frame, TMD with 6% mass ratio is found to have better storey displacement and storey drift control. Percentage reduction in maximum storey displacement is 53.298% and percentage reduction in maximum storey drift is 48.613%.

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REFERENCES

[1] Balachandar M and Vinod Y (2018), "Control of vibrations in building due to seismic force using tuned mass damper", International Journal of Civil Engineering and Technology, Volume 9, Page No. 373–1379.

[2] Praveen J V and Anusha H P (2018), "A comparative study of RC framed structures using passive control devices as soft storey", International Journal of Engineering Research & Technology, Volume 7, Page No. 332-336.

[3] Sanket Shivastava, et.al (2019), "Analytical Comparison of a G + 8 Storey Residential Building with Tuned Mass Damper and Practical Tuned Mass Damper", International Research Journal of Engineering and Technology, 6, 497-503

[4] Midhun Krishnan R and Dr. C K Prasad Varma Thampan (2016), "A study on vibration control of framed structures due to seismic excitation using tuned mass damper", International Journal of Scientific & Engineering Research, Volume 7, Page No. 282-286.

[5] Raveesh R. M and Sahana T. S (2014), "Effect of tuned mass dampers on multi-storey RC framed structures", International Journal of Engineering Research & Technology, Volume 3, Page No. 1115-1125.

[6] Thakur V. M and Pachpor P D (2012), "Seismic analysis of multi-storied building with TMD", International Journal of Engineering Research and Applications, Volume 2, Page No. 319-326.

[7] Pavithra R and Dr. T M Prakash (2018), "Study of behaviour of the soft storey at different locations in the multi-storey building", International Journal of Engineering Research & Technology, Volume 7, Page No. 53-59.

[8] Dr. S.A. Halkude C G Konapure and Vanishri S Kulkarni, (2017), "Seismic analysis of structure by introducing weak story on top as tuned mass damper", International Journal for Research in Applied Science & Engineering Technology, Volume 5, Page No. 1321-1327.

[9] Sayed Mahmoud, Magdy Genidy and Hesham Tahoon (2016), "Time history analysis of reinforced concrete frame buildings with soft storeys", Arabian Journal of Science and Engineering.

[10] Venkata Ramana G and Vinod Y (2019), "Combined strategy of building vibration control by using tuned mass damper and base isolator", International Journal of Recent Engineering and Technology, Volume 7, Page No. 289-292.

[11] Hosein Naderpour, Naghmeh Naji , Daniel Burkacki and Robert Jankowski (2019), "Seismic response of high-rise buildings equipped with base isolation and non-traditional tuned mass dampers", Multidisciplinary Digital Publishing Institute.

[12] Zheng Lu, Biao Huang, Zixin Wang and Ying Zhou (2018), "Experimental comparison of dynamic behaviour of structures with a particle damper and a tuned mass damper", Journal of Structural Engineering.

[13] Bibin Mathew and Ms. Anu A, (2015), "Vibration control of high-rise structures by using tuned mass dampers", International Journal of Engineering Research & Technology, Volume 3, Page No. 1-5.

[14] G.S. Balakrishna and Jini Jacob (2014), "Seismic analysis of building using two types of passive energy dissipation devices", Page No. 13-19.