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A Study on Vibration Control of Structures due to Seismic Excitation using Tuned Mass Damper

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Abstract— In recent years, tall buildings are very common, and they are flexible and having low damping capacity. Tall buildings vibrated under strong winds and earthquakes become uncomfortable for occupants. Therefore, various types of dampers are being developed in recent years to reduce the vibration in those structures. Recently dampers have become more popular for vibration control of structures, because of their safe, effective and economical design. Tuned mass damper (TMD) is a passive control device which absorbs energy and reduces vibration response of structures. This paper addresses the usefulness of incorporating soft storey to function as TMD in controlling the structural response. An attempt is made to find the effective mass ratio which gives the least displacement of the building. Here a six storeyed asymmetric building with re-entrant corner is analyzed by a soft storey placed at top of building to act as TMD with varying mass ratios 2%, 3% and 4%. Time history analysis was carried out by applying standard earthquake ground accelerations. A comparative study was done. The optimum mass ratios obtained for both symmetric and asymmetric buildings were 3%.

Index Terms— Asymmetric building, Free vibration characteristics, Non linear time history analysis, Optimum parameters, Seismic behavior, Tuned mass damper, Vibration control.

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1 INTRODUCTION

An earthquake is a natural phenomenon with violent shaking of the ground. Sudden movements of earth crust mostly due to tectonic movements caused vibrations of the earth's surface. With the rapid economic development and advanced technology, structures such as high-rise buildings, towers and long span bridges are designed with an additional flexibility, which lead to an increase in their susceptibility to external excitation. There are two basic technologies are used to control and protect buildings from damage during earthquakes. These are seismic dampers and base isolation devices. Energy dissipation dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building. Recently the dampers have become more popular for vibration control of structures, because of their safe, effective and economical design. Based on the functions or control system the damper can be classified into various categories. The passive tuned mass damper (TMD) is very reliable, simple, effective, and inexpensive means to suppress undesirable vibrations of structures caused by harmonic or wind excitations. A Tuned mass damper is an energy dissipation device consisting of a mass, and spring that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the tuned mass damper is tuned to a particular structural frequency. So that, when the same frequency is excited, the damper will resonate out of phase with the structural motion. In this the energy is dissipated by the damper inertia force acting on the building. To reduce the rolling motion of ships as well as ship hull vibrations, the Tuned Mass Damper (TMD) concept was first applied by Frahm in 1909.

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2 TUNED MASS DAMPER

TMD is a passive damper. Some mass additional to the system is attached on it and is tuned to the frequency of the structure. Generally, the tuned mass dampers are installed at the top of a building. The damper installation requires large space. These dampers are usually suspended at the top and are tuned to one of the fundamental frequency of the building (generally first mode). The light weight and flexible structure to overcome the inertia of a great mass due to presence of a tuned damper.

These dampers are suitable only when the structure responds significantly in one mode. The amplitudes and frequencies of the TMD and the structure should match so that every time the wind pushes the building, the TMD creates an equal and opposite push on the structure, and keeping its horizontal displacement at or near zero. When their frequencies were different, the tuned mass damper would create pushes that were out of sync with the pushes from the wind, and the building's motion would still be uncomfortable for the occupants. If their amplitudes were different, the tuned mass damper would, for example, create pushes that were in sync with the pushes from the wind but not quite the same size and the building would still experience too much motion.

These dampers occupy large valuable space at the top of the building. Therefore, instead of single TMD, multiple small TMD's along the height of the structure can be installed to effectively control the response of the structure. These TMD's can also take care of the response of the structure due to higher modes. If some of the TMD's cannot function properly then

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remaining TMD's will control the response of the structure. The tuned mass dampers are tuned along the height of the structure depending on the mode shapes of the structure.

The effectiveness of a TMD is dependent on the mass ratio (of the TMD to the structure itself), the ratio of the frequency of the TMD to the frequency of the structure, and the damping ratio of the TMD.

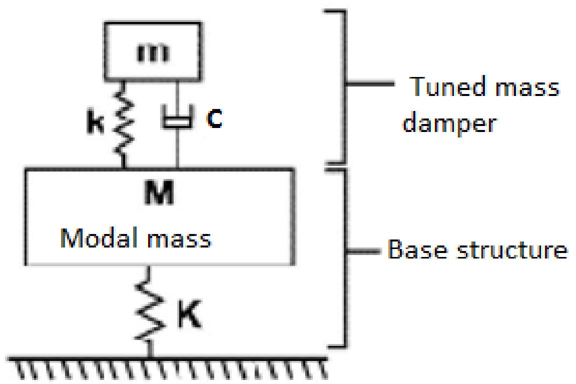

Fig. 1 Base structure with TMD system

Fig. 2 Tuned mass damper

2.1 Soft storey

When the quick change of stiffness takes place along the height of the structure, the storey where the drastic reduction of stiffness is observed is known as soft storey.

As per IS-1893:2002 (part I)
A Soft Storey is one in which the lateral stiffness is less than 70 percent of that in the storey immediately above or below or less than 80 percent of the average lateral stiffness of the three storeys immediately above or below.

2.2 Time history analysis

Here non-linear time history analysis is done using finite element software ETABS. The results computed by the nonlinear dynamic procedure can be highly sensitive to characteristics of individual ground motions, the analysis should be carried out with more than one ground motion record. FEMA 356 provides guidelines regarding the required number of ground motions that should be used for dynamic analysis. Here 25 earthquakes with different intensities are applied to the building and analyzed.

3 MODELLING AND ANALYSIS

3.1 Analysis software

For the present study the software ETABS is used and the salient features of the same are presented.
The following elements are expected to be used in the analysis

- Frame elements

It is used to model beams, columns, braces, and trusses
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- Shell elements

A shell element is used to model walls, floors, and other thin-walled members.

B. Building Description
(i). Structural Configuration
It is an asymmetric building with 6 storeys. The storey height is 3m.

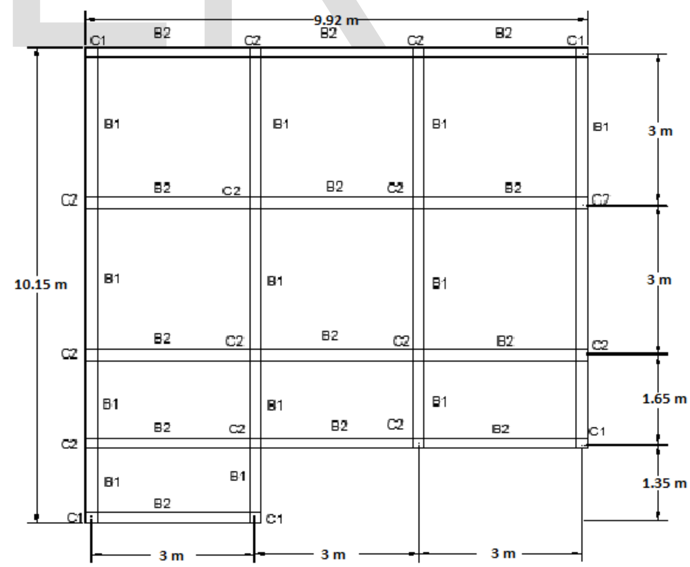

Fig. 3 Plan of the building

(ii). Loads Considered
Materials
Grade of concrete – M20
Grade of steel – Fe415

Dead Loads (Unit Weights)
Masonry – 21.2 KN/m3
Concrete - 25 KN/m3
Steel - 78.54 KN/m3
Imposed loads
Floor loads - 4 KN/m2
Roof loads - 1.5 KN/m2

Table 1 Dimensions of structural elements

Sl. No	DIMENSION
1	C1 – 230x230 mm
2	C2 – 230x400 mm
3	B1 – 230x400 mm
4	B2 – 230x400 mm
5	Slab- 100 mm thick

Initially the grid sections are defined according to the building dimensions. Then the properties of the material as well as the beam and column properties were defined. Then the required building was drawn using the beam, column and slab sections that were defined earlier. The extruded view of the building shown in figure 4.

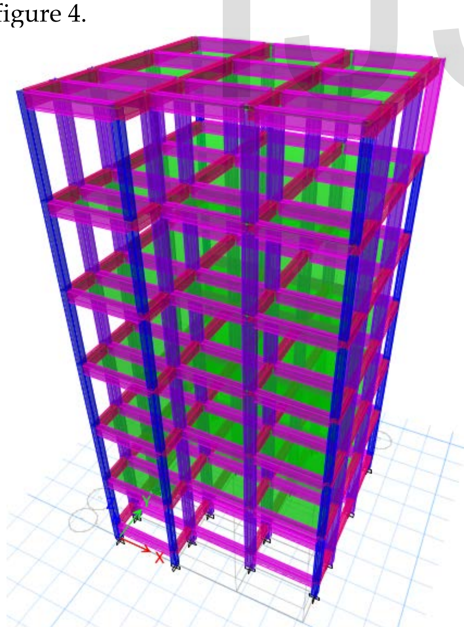

Fig. 4 Model of the building

Table 2 Details of TMD for the building

Mass Ratio (%)	Column size (mm)		Beam Size (mm)		Slab Thickness
	C1	C2	B1	B2	
2	78x78	78x160	78x160	78x180	80
3	100x100	100x160	100x250	100x280	115
4	130x130	130x200	130x250	130x280	150

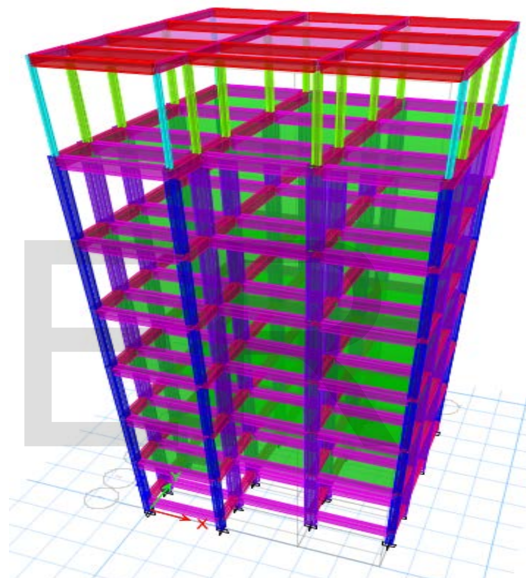

Fig. 5 TMD in the form of soft storey placed at the top of the building

4 RESULTS AND DISCUSSIONS

After analyzing the structure for different earthquakes with different magnitudes, the values of the maximum displacements at the top of the building are obtained and are tabulated in tables.

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Table 3 Displacement at the top of the building-X excitation

Sl no	Earthquake	Station	Without TMD	2%	3%	4%
1	Imperial Valley	El Centro Array # 3	9.6814	7.6357	9.6217	9.9919
2	Imperial Valley	El Centro Array # 4	17.4162	16.1559	16.0008	17.2222
3	Imperial Valley	El Centro Array # 5	27.1686	20.8252	20.7089	21.9603
4	Imperial Valley	El Centro Array#8	20.8671	19.8096	18.8884	20.2234
5	Imperial Valley	El Centro Array#10	8.9881	8.8855	7.4125	8.9299
6	Imperial Valley	El Centro Array#11	9.02279	7.0834	7	9
7	Imperial Valley	Delta	70.9639	67.5040	65.7337	69.3248
8	North Ridge	LA-OCLA Grounds	53.0262	50.8139	48.3693	52.3766
9	North Ridge	LA-univ.hospital	58.1698	56.7175	44.4771	51.5148
10	North Ridge	Moorpark firestation	55.3555	54.6453	49.2563	55.111
11	North Ridge	NHollywood coldwatercan	53.4311	51.2706	50.1380	53.111
12	North Ridge	Canogapark	114.8492	88.6339	80.5208	103.8632
13	North Ridge	Canyon country	141.5676	90.5634	88.4296	126.1644
14	North Ridge	Castaic old ridge	83.923078	82.1062	81.3851	82.5556
15	Loma Prieta	Fastercity-APEEL 1	28.8145	27.9833	23.2694	27.2107
16	Loma Prieta	Gilroy Array#3	11.9114	10.7245	3.1874	11.666
17	Loma Prieta	Gilroy Array#4	63.9697	12.5993	10.7347	60.9696
18	Loma Prieta	LPGC	293.5843	282.6726	280.6846	288.2959
19	Loma Prieta	Fremont-mission san jose	32.9817	31.9425	30.7051	32
20	Loma Prieta	WAHO	87.7098	86.6543	80.2496	85.3770
21	Morgan hill	Gilroy Array#4	10.7187	9.4586	9.0011	10.566
22	Morgan hill	Gilroy Array#6	20.9638	20.1167	19.9981	20.9556
23	Superstation hill	Elcentro Imp.co.cent	89.7523	78.7516	73.3494	85.1918
24	Kobe	Yae	60.5570	59.0208	58.7953	59.7385
25	Dueze	Bolu	150.1749	100.0868	99.0022	111.9047

Table 4 Displacement at the top of the building-Y excitation

Sl no	Earthquake	Station	Without TMD	2%	3%	4%
1	Imperial Valley	El Centro Array # 3	84.8413	79.1867	75.3624	76.478
2	Imperial Valley	El Centro Array # 4	172.7278	79.1016	75.2453	160.9818
3	Imperial Valley	El Centro Array # 5	114.0209	64.5343	63.8039	110.976
4	Imperial Valley	El Centro Array#8	95.7933	76.3305	74.2561	92.0622
5	Imperial Valley	El Centro Array#10	29.7010	28.3196	27.8302	28.9999
6	Imperial Valley	El Centro Array#11	62.0980	60.7719	58.3726	60.9099
7	Imperial Valley	Delta	98.1461	79.6023	75.2910	88.2313
8	North Ridge	LA-OCLA Grounds	58.2425	54.7724	50.0422	55.7227
9	North Ridge	LA-univ.hospital	31.2324	29.6510	26.3035	28.1157
10	North Ridge	Moorpark firestation	55.3555	49.1260	30.0727	49.7264
11	North Ridge	NHollywood coldwatercan	74.6261	74.0945	70.9112	73.3675
12	North Ridge	Canogapark	138.6843	78.6967	76.6006	130.8615
13	North Ridge	Cnyon country	150.2989	147.9999	140.6356	148.4694

14	North Ridge	Castaic old ridge	226.8521	156.1087	145.3388	178.5091
15	Loma Prieta	Fastercity-APEEL 1	87.4462	85.1366	83.9745	85.0081
16	Loma Prieta	Gilroy Array#3	104.4048	81.3857	9.9456	89.8899
17	Loma Prieta	Gilroy Array#4	89.6766	69.7557	67.6803	87.9351
18	Loma Prieta	LPGC	235.5343	209.8712	207.4284	186.5945
19	Loma Prieta	Fremont-mission san jose	30.7890	12.5714	10.8781	30.1980
20	Loma Prieta	WAHO	155.1917	82.0928	80.5679	150.9811
21	Morgan hill	Gilroy Array#4	45.1867	43.0934	42.5264	44.5882
22	Morgan hill	Gilroy Array#6	45.0359	32.7761	31.1056	39.6313
23	Superstation hill	Elcentro Imp.co.cent	39.8210	38.2827	30.9262	36.4747
24	Kobe	Yae	86.3547	71.5009	58.7963	72.6949
25	Dueze	Bolu	310.5291	225.8406	220.7743	308.7424

Table 5 Rotation of the building

SL No	Earthquake	Station	Without TMD	2%	3%	4%
1	Imperial Valley	El Centro Array # 3	0.000824	0.000741	0.000694	0.000744
2	Imperial Valley	El Centro Array # 4	0.000622	0.000593	0.000404	0.000415
3	Imperial Valley	El Centro Array # 5	0.001302	0.000918	0.000831	0.000866
4	Imperial Valley	El Centro Array#8	0.000624	0.000612	0.000542	0.000612
5	Imperial Valley	El Centro Array#10	0.001528	0.001223	0.001011	0.001105
6	Imperial Valley	El Centro Array#11	0.00122	0.00120	0.00112	0.00121
7	Imperial Valley	Delta	0.000981	0.000967	0.000834	0.000835
8	North Ridge	LA-OCLA Grounds	0.000756	0.000661	0.000659	0.000666
9	North Ridge	LA-univ.hospital	0.000992	0.000817	0.000812	0.00088
10	North Ridge	Moorpark firestation	0.000656	0.000558	0.000556	0.000624
11	North Ridge	NHollywood coldwatercan	0.000776	0.000714	0.000683	0.000750
12	North Ridge	Canogapark	0.00113	0.000972	0.000882	0.000981
13	North Ridge	Cnyon country	0.00123	0.00120	0.00111	0.00121
14	North Ridge	Castaic old ridge	0.000521	0.000432	0.000334	0.000449
15	Loma Prieta	Fastercity-APEEL 1	0.00105	0.00082	0.000811	0.000823
16	Loma Prieta	Gilroy Array#3	0.000432	0.000365	0.000347	0.000366
17	Loma Prieta	Gilroy Array#4	0.00213	0.00210	0.0018	0.00211
18	Loma Prieta	LPGC	0.000589	0.0000459	0.000442	0.000462
19	Loma Prieta	Fremont-mission san jose	0.00257	0.00246	0.0020	0.00248
20	Loma Prieta	WAHO	0.00300	0.00289	0.00252	0.00299
21	Morgan hill	Gilroy Array#4	0.00256	0.00248	0.00218	0.00250
22	Morgan hill	Gilroy Array#6	0.00211	0.00179	0.00136	0.00184
23	Superstation hill	Elcentro Imp.co.cent	0.000781	0.000645	0.000634	0.000649
24	Kobe	Yae	0.00648	0.000640	0.000521	0.000643
25	Dueze	Bolu	0.000527	0.000520	0.000487	0.000525

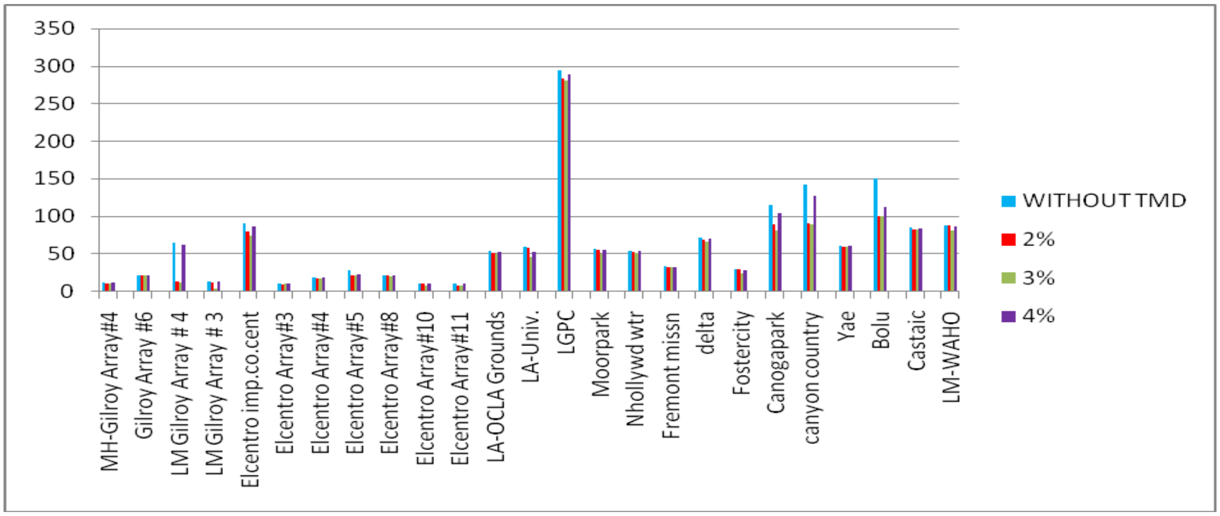

Fig. 6 Displacement at the top of the building – X –excitation

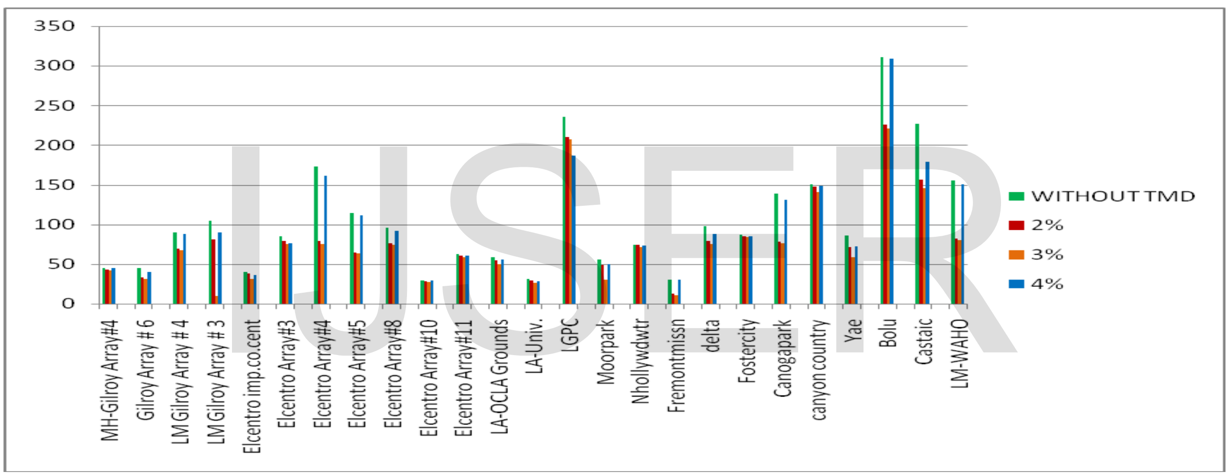

Fig. 7 Displacement at the top of the building – Y-excitation

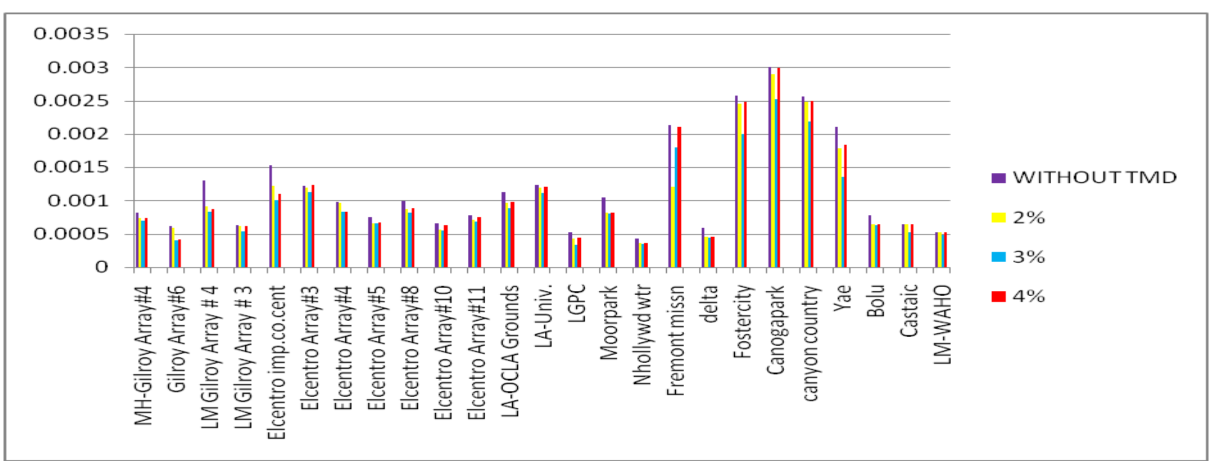

Fig. 8 Rotation of the building

Table 6 Percentage reduction in displacements – X-excitation

Percentage Reduction in Displacements		
2% TMD	3% TMD	4% TMD
17.40%	21.44%	9.24%

Table 7 Percentage reduction in displacements – Y-excitation

Percentage Reduction in Displacements		
2% TMD	3% TMD	4% TMD
23.335%	30.04%	7.099%

Table 8 Percentage reduction in rotation

Percentage Reduction in Displacements		
2% TMD	3% TMD	4% TMD
12.885%	20.555%	9.4522%

The plots of percentage reduction in displacements at the top of the building in Xand Y-excitations and mass ratio of TMD's is also shown below.

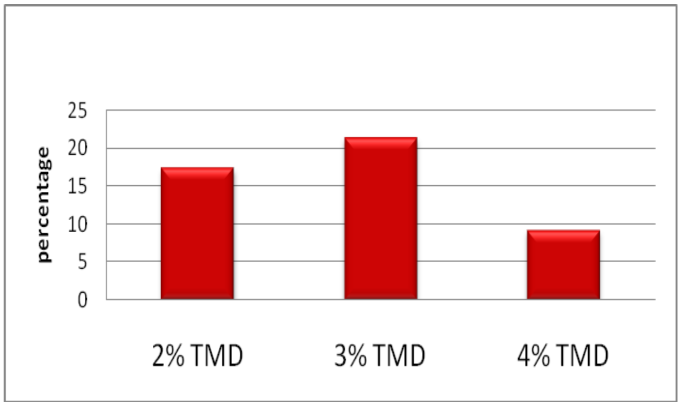

Fig. 9 Percentage reduction in displacements – X-excitation

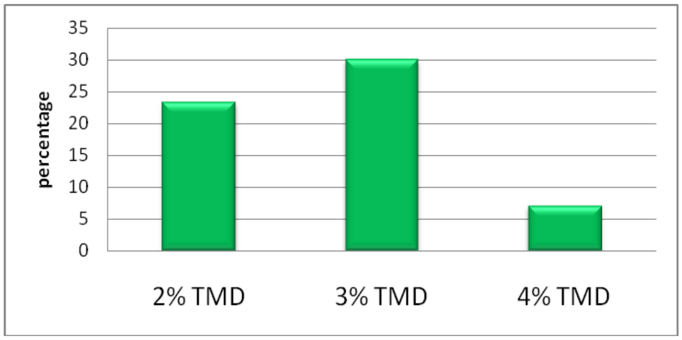

Fig. 10 Percentage reduction in displacements – Y-excitation

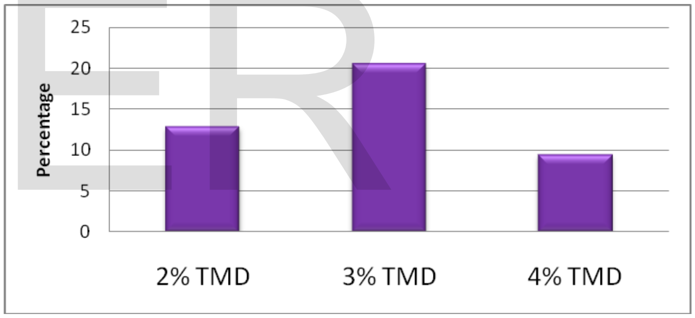

Fig. 11 Percentage reduction in rotation

5 Conclusion

After the analysis of asymmetric building with and without Tuned Mass Damper, following are the conclusions.

- It has been found that the TMDs can be successfully used to control vibration of the structure.
- In general, a soft storey at the top of building reduces deflection at top building by about 10 to 25%
- Among the 2%, 3% and 4% TMD's, the effectiveness varies according to the earthquake ground motion data, and 3% TMD is found to be the most effective among all on a statistical basis.

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