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ANALYSIS OF TUNED MASS DAMPER IN HIGH-RISE STRUCTURES

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Abstract — ***The present work aims to demonstrate the performance of building. Here, models of 15,25 and 40 storeys without and with TMD were prepared by considering symmetrical R.C moment resisting frame. Tuned Mass Dampers with varying mass ratio of 3% applied. Analysis of NLTH is done utilizing 1893:2002 for designing a RCMRF structure for seismic force and gravity load. It has been proposed to develop a suitable TMD that should be effective enough to reduce base shear, story drift, story displacement etc. for doing so optimal parameters of TMD where calculated using Den hutong's equation and parameters like frequency ratio, damping ratio, effective stiffness of TMD and effectual TMD damping. Using this parameters TMD was modeled in SAAP 2000 and result where compared with TMD and without TMD***

KEYWORDS- TMD, NONLINEAR DYNAMIC ANALYSIS, TIME HISTORY ANALYSIS, SAAP 2000

I. INTRODUCTION

Nowadays tall buildings are indispensable in built up areas due to high economy of land, lack of lands, and deficiency of open space. The tall buildings are in general highly powerless to lateral forces arising out of earthquakes. Designing these structures to withstand these occasional lateral forces is very expensive; hence it is not eternally desirable. Any appropriate mechanism is proposed to eliminate the effect of lateral forces on structure is highly inspirited. Over a time period, a research was going on to know the methods for reduction of the lateral force, the amplitudes of vibration and the frequency of the structure using different approaches. Among this, the most familiar methods are the base isolation and the introduction of TMD.

Tuned mass damper: Tuned mass dampers (TMD) have been usually make use for vibration control in mechanical engineering system. As of late, TMD hypothesis has been utilized to decrease vibrations of tall structures and other structures of civil engineering. Tuned mass dampers and Dynamic absorbers are the apprehension of tuned absorber and tuned damper for applications in control vibration of structures. The inertial, flexible, and dissipative components in such mechanism are: mass, spring and dashpot (or material damping) for linear applications and their turning counterparts in rotational applications. Depending on the application, these devices are measured from a few ounces (grams) to numerous tons. Different setups, for example, sloshing liquid absorbers/dampers and pendulum absorbers/dampers have likewise been acknowledged for vibration mitigation applications TMD involves in positioning of a structure over an existing building and also reducing the effect of dynamic loads. The TMD will have certain stiffness, damping and mass. Tuning of TMD refers to suitably adjusting the value of stiffness, damping and mass to eliminate the dynamic outcome of a given building subjected to dynamic forces /displacement. However not much of headway was made in the field of TMD due to absence of rational theories of structural dynamics. The mass is for the most part joined to the building via a spring-dashpot system and energy is dispersed by the dashpot as relative motion is created between the mass and the structure. The following are the objectives of this study:
To review Seismic demand of regular Reinforced concrete building utilizing the nonlinear dynamic analysis.
To study the impact on the response of the High-rise Symmetric Buildings with TMD (Tuned mass damper).
To study various responses such as B.S, Overturning moment, S.F, BM, axial force, storey drift, storey shear, etc., of structures.

II. LITERATURE REVIEW

Pachpor P D, Thakor V.M (2012) in their study i.e., on "Seismic analysis of Multi-storeyed Building with Tuned mass damper, for the analysis they considered a rectangular shape 6 storied building. They utilised TMD as a soft storey which is said to be made up of RCC, constructed at the top of the building. They appraise TMDs with 2 and 3% of percentage masses. They utilised direct integration approach and perform the analysis with SAP 2000 FE software. They appraise 3 different recorded time histories of past Earthquakes for the analysis. The results were compared for the models without and with TMDs .At last they presumed that TMD with optimum frequency ratio, provided in the form of soft storey at building top is found to be effective in diminishing seismic response of building and also TMD with 3% is found to be effective compared to TMD with 2% mass ratio in reducing axial force, bending moment, etc.

Hossein Shad and Azlan Adnan (2013) in their study i.e., on “An investigation on the effectiveness of TMD in suppressing the displacement response under harmonic load”, studied the simplification of utilizing TMD for controlling the vibration of the buildings by considered the FE software under harmonic analysis. A 5-storey building with TMD was modelled. A spring mass system instead of mass damper was considered at different level of storeys. The final results for displacements response of structures for various models were compared and at last they concluded that with increasing TMD mass ratio results in increment in the displacement reactance of the structure.

Raveesh R M and Sahana T S (2014) in their study i.e., on “Effect of TMD on Multi-storey RC Framed Structures”, carried on the investigation on considering the multi-storey RC frame structure buildings having height to breadth ratio of 1,2,3. The models prepared were (G+9), (G+19), (G+29) storeys with mass ratio 0.25,0.5,0.75 and considered the models to represent the buildings situated in zone-V. The characteristics reviewed were natural time period, base shear, roof displacement and lateral displacement. For generating the singe record Time Vs Acceleration curve, a single ground motion was utilised namely Bhuj Earthquake. The analysis work was done in SAP 2000.They finally concluded that TMD was effective in decreasing the parameters and with TMD mass ratio of 0.25 being most effective when compared to TMD with 0.5,0.75 mass ratios.

FahimehHoseinzadeh , D. Rupesh Kumer (2015) in their study i.e., on “A Study On impact of water tanks modeled as TMDs on Dynamic properties of structures, the modeling was done with suitable TMD system on the intermediate storey of building. They adopted the Response spectrum regulations according to 1893-2002 of IS part1. They considered seven RCC frame buildings in which three models of 10,14 and 20 storey were with vertical irregularity having 0.875,1.23,1.6 as the H/D ratios, one model of 14 storey was L-shaped with 1.23 as H/D ratio and three models of 10,14 and 20 storeys were with vertical regularity having 3.9,5.44,8.4 as H/D ratio. By considering 3% total weight of each floor and using 8 different cases modeling of TMDs was done. The analysis process was done utilizing ETABS software and in total 63 buildings were modeled. For having maximum benefits, they modeled the buildings with three TMDs with 3 Gauss points at the intermedial storey which in turn reduces time period, Base shear, Storey drift simultaneously to the maximum possible extent.

III. METHODOLOGY

A. Principle of TMD (Tuned Mass Damper)

TMD is a vibration arrangement containing the mass, springs and dampers are situated on the top of structures as view in figure below. It is elated by the agitation of the structure when the structure begins to vibrate. Thus, the structure generates the kinetic energy which is directed into TMD device in order to consume by the viscous damper of TMD. For accomplishing more effective energy observing capacities of TMD, the original time of TMD device without anyone else input will tune with the original time of the building by itself from which the system is known as "Tuned Mass Damper". As a matter it is easily maintainable and highly dependable, TMD is also used in lightly-damped buildings as in earthquake prone countries.

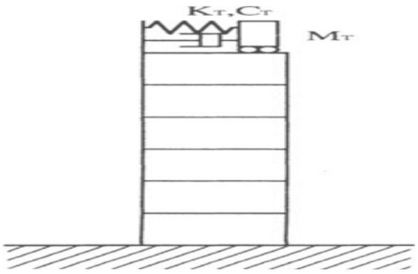


Figure 1 showing tuned mass damper on a building

B. Determination of the Optimum TMD

The TMD effectively reduces dynamics responses of a single vibration zone of the building. In reality, buildings have several vibrations zone, basic properties of TMD can be clearly discussed by considering simplified 2-DOF models containing the main building and the TMD system. The parameters used are defined as follows.

Natural-Frequency of TMD $\omega_T = \sqrt{\frac{K_T}{m_T}}$, Damp-Ratio of TMD $\xi_T = \frac{C_T}{2m_T\omega_T}$, Natural-Frequency of Main Structure $\omega_S = \sqrt{\frac{K_S}{m_S}}$, Damp-Ratio of Main Structure $\xi_S = \frac{C_S}{2m_S\omega_S}$, Mass-Ratio $\mu = \frac{m_S}{m_T}$, Frequency (Tuning) Ratio $\gamma = \frac{\omega_T}{\omega_S}$

Dan Hertog defines the optimum TMD by allowing the two well defined point the actual values and has higher possibilty in the DMF curve. The physical state of this is to obtain flat DMF curve at the resonant frequency, and consequently to suppress the dynamic response of the main structure most effectively. The optimum frequency-ratio γ_{opt} and the optimum damp-ratio ξ_{Topt} of TMD are obtained by Dan Hertog as function of mass ratio μ, i.e.,

$\gamma_{opt} = \frac{1}{1+\mu}$, $\xi_{Topt} = \sqrt{\frac{3\mu}{(1+\mu)8}}$

C. Description of All Models

In the present study 15,25,40 storey models have been considered with and without Tuned mass damper. The buildings having tuned mass damper was placed at the Centre of top floor or CG of the buildings with mass ratio 3% is applied. In total 6 models were prepared. For 15,25,40 storey models with and without TMD the following parameters were considered.

Type of structure	SMRF
Plan Dimension	(36 x 36) m
Number of Bays	6
Size of each Bays	6m
Number of Storey's	G+14
Storey Height	3.0m
Grade of Concrete	
Beams	M30
Columns	M30
Slabs	M30
Grade of Steel	FE415
Beam Size	0.45 X 0.45 m
Column Size	0.60 x 0.60 m
Slab Thickness	0.15 m
Wall Thickness	0.23 m
Load Calculation	
Self Weight Of Wall on Each Floor	12.00 KN/sq.m
Live Load	3 KN/sq.m
Floor Finish	1 KN/sq.m
Earthquake Analysis as per IS 1893:2002	
Seismic Zone	V
Zone factor	0.36
Importance factor	1
Response Reduction factor	5
Wind Analysis as per IS 875 part 3	
Wind Speed	50 m/s
Terrain Category	2
Structure class	B
Risk Coefficient, k1	1
Topagraphy, k3	1

a. For 15 Storey Building

Type of structure	SMRF
Plan Dimension	(36 x 36) m
Number of Bays	6
Size of each Bays	6m
Number of Storey's	G+24
Storey Height	3.0m
Grade of Concrete	
Beams	M30
Columns	M30
Slabs	M30
Grade of Steel	FE415
Beam Size	0.45 X 0.45 m
Column Size	0.60 x 0.60 m
Slab Thickness	0.15 m
Wall Thickness	0.23 m
Load Calculation	
Self Weight Of Wall on Each Floor	12.00 KN/sq.m
Live Load	3 KN/sq.m
Floor Finish	1 KN/sq.m
Earthquake Analysis as per IS 1893:2002	
Seismic Zone	V
Zone factor	0.36
Importance factor	1
Response Reduction factor	5
Wind Analysis as per IS 875 part 3	
Wind Speed	50 m/s
Terrain Category	2
Structure class	C
Risk Coefficient, k1	1
Topagraphy, k3	1

b. For 25 Storey Building

Type of structure	SMRF
Plan Dimension	(36 x 36) m
Number of Bays	6
Size of each Bays	6m
Number of Storey's	G+39
Storey Height	3.0m
Grade of Concrete	
Beams	M30
Columns	M30
Slabs	M30
Grade of Steel	FE415
Beam Size	0.45 X 0.45 m
Column Size	0.60 x 0.60 m
Slab Thickness	0.15 m
Wall Thickness	0.23 m
Load Calculation	
Self Weight Of Wall on Each Floor	12.00 KN/sq.m
Live Load	3 KN/sq.m
Floor Finish	1 KN/sq.m
Earthquake Analysis as per IS 1893:2002	
Seismic Zone	V
Zone factor	0.36
Importance factor	1
Response Reduction factor	5
Wind Analysis as per IS 875 part 3	
Wind Speed	50 m/s
Terrain Category	2
Structure class	C
Risk Coefficient, k1	1
Topagraphy, k3	1

c. For 40 Storey Building

MODEL-1 15-STOREY NORMAL BUILDING WITHOUT TMD

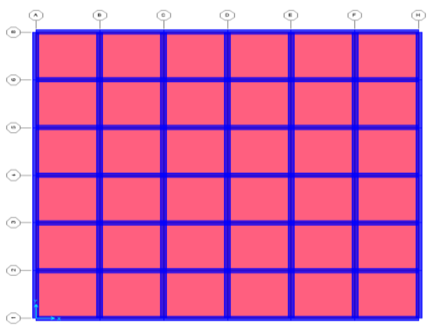


Fig.2 Plan view of model-1 15-storey normal building normal building

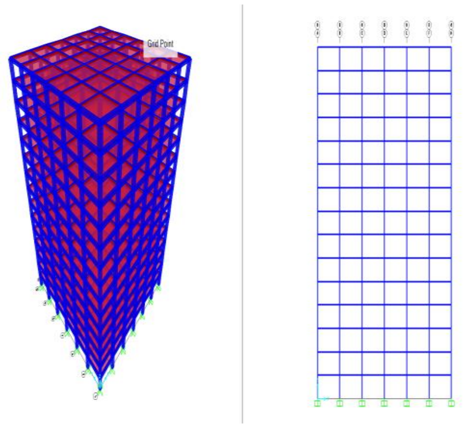


Fig.3 3D view and elevation of model-1 15-storey

MODEL-2 15-STOREY NORMAL BUILDING WITH TMD

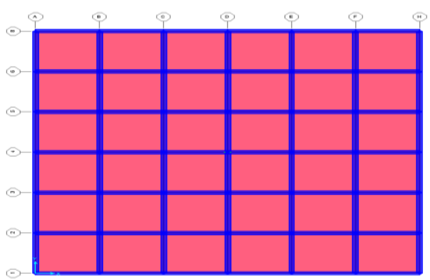


Fig.4 Plan view of model-2 15-storey normal building with TMD normal building wit TMD

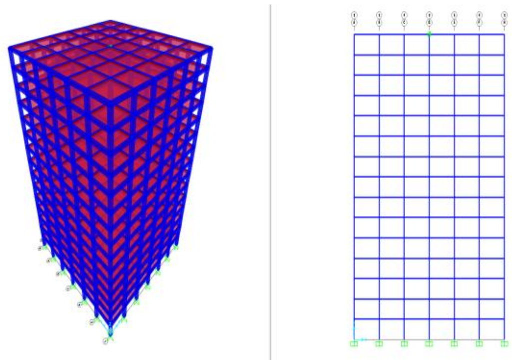
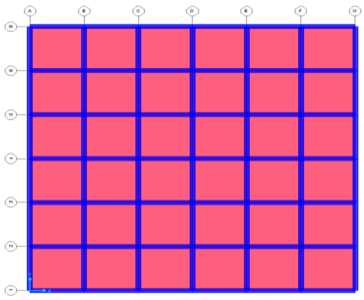


Fig 5 3D view and elevation of model-2 15-storey

MODEL-3 25-STOREY NORMAL BUILDING WITHOUT TMD



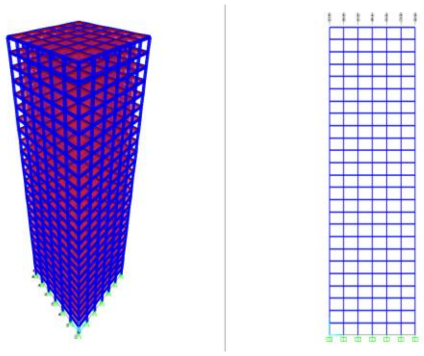
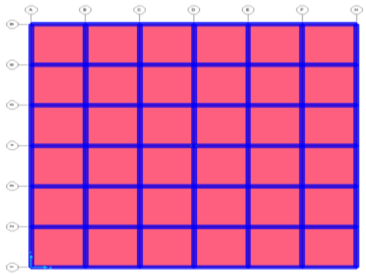


Fig.6 Plan view of model-3 25-storey normal building

Fig.7 3D view and elevation of model-3 25-storey normal building

MODEL-4 25 STOREY NORMAL BUILDING WITH TMD



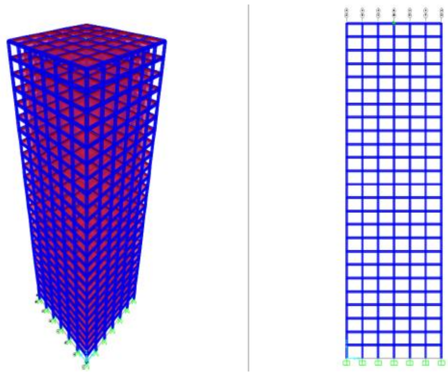
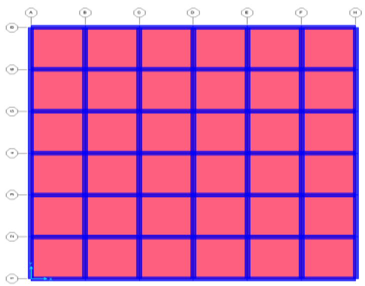


Fig.8 Plan view of model-4 25-storey normal building with TMD

Fig.9 3D view and elevation of model-4 25-storey normal building with TMD

MODEL-5 40 STOREY NORMAL BUILDING WITHOUT TMD



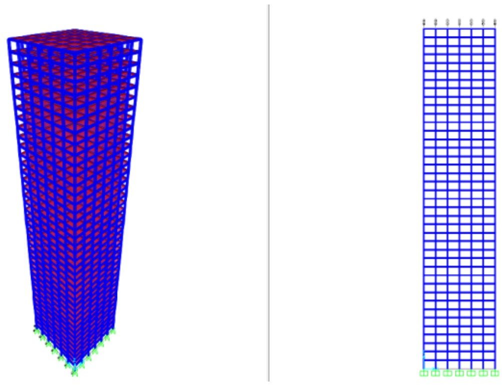
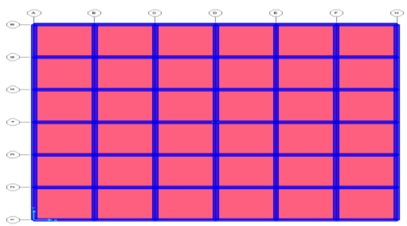


Fig.10 Plan view of model-5 40-storey normal building

Fig.11 3D view and elevation of model-5 40-storey normal building

MODEL-6 40-STOREY NORMAL BUILDING WITH TMD



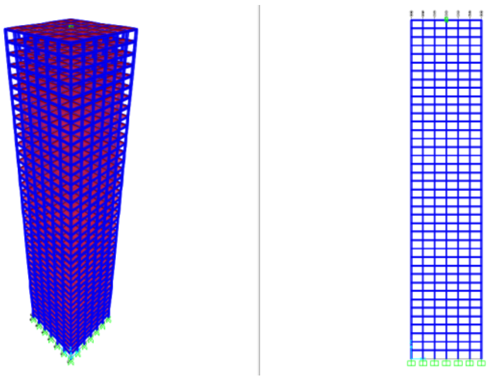


Fig.12 Plan view of model-6 40-storey normal building with TMD

Fig.13 3D view and elevation of model-6 40-storey normal building with TMD

IV. RESULTS AND DISCUSSION

A. *For Model-1(Without TMD) and Model-2(With TMD)*

1. Storey Displacement in x & y direction

STOREY NO.	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
	Ux & Uy	Ux & Uy
15	918.1	584.08
14	890.25	568.85
13	855.09	548.01
12	811.38	522.11
11	772.7	491.72
10	722.11	457.27
9	660.72	419.00
8	591.06	377.06
7	516.04	331.64
6	440.14	283.07
5	367.78	231.90
4	292.95	178.8
3	210.00	125.04
2	123.6	72.23
1	43.7	25.24

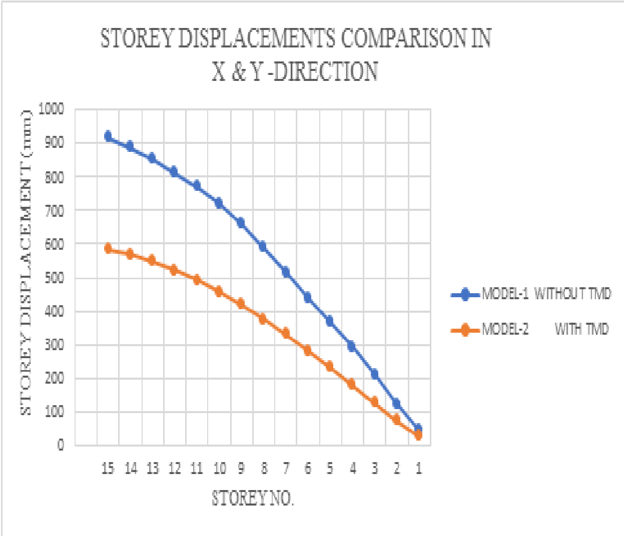


Table 1 Storey Displacement (mm) comparison in x & y -direction

Figure 13 displays the storey displacements comparison of model-1 and model-2 in x & y -directions. From the figure, it can be observed that storey Displacement of model-2 is reduced by about 36.38% having TMD when compared to model-1 having no TMD at the top storey.

2. Storey Drift in x & y direction

STOREY NO.	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
	Ux & Uy	Ux & Uy
15	27.85	15.23
14	35.16	20.84
13	43.71	25.9
12	38.68	30.39
11	50.59	34.43
10	61.39	38.27
9	69.64	41.94
8	75.02	45.42
7	75.9	48.57
6	72.36	51.17
5	74.83	53.09
4	82.95	53.77
3	86.4	52.81
2	79.9	46.99
1	43.7	25.24

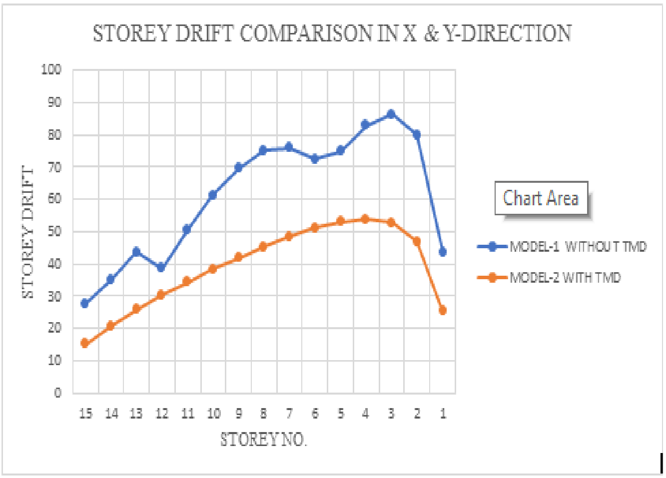


Table 3 Storey Drift comparison in x & y -direction

Figure 14 displays the storey drift comparison of model-1 and model-2 in x & y-direction. From the figure, it can be observed that at the top storey, storey drift of model-2 is reduced byabout 45.3% having TMD when compared to model-1 having no TMD at the top storey.

3. Time Period

MODE NO.	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
1	2.15	1.44
2	2.15	1.44
3	1.96	1.236
4	0.70	0.466
5	0.70	0.466
6	0.64	0.403
7	0.40	0.264
8	0.40	0.264
9	0.36	0.246
10	0.27	0.232
11	0.271	0.177
12	0.251	0.177

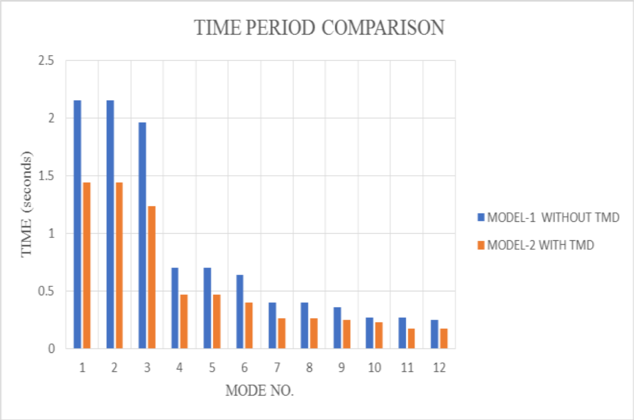


Table 5 Time period(seconds) comparison

Figure 16 displays the Time period comparison of model-1 and model-2.From the figure it is seen that time period of mode-1 of model-2 having TMD is reduced by about 33.06% when compared to mode-1 of model-1 with no TMD.

4. Base Shear in x & y direction

	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
Base Shear	83900	38640

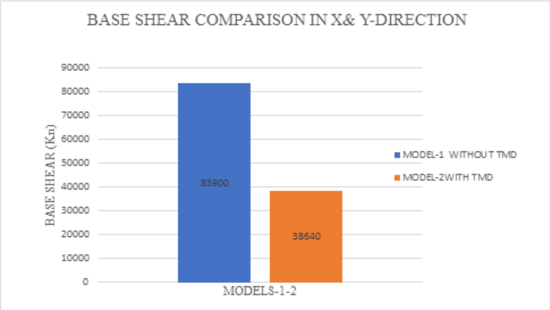


Table 6 Base shear(Kn) comparison in x&y-direction

Figure 17 displays the base shear comparison of Model-1 and Model-2 in the x&y- direction. It is observed that TMD reduces base shear of Model-2 by 53% when compared to Model-1 having no TMD.

5. Base Moment in x & y direction

	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
Base Moment	1.225x10^9	7.05x10^8

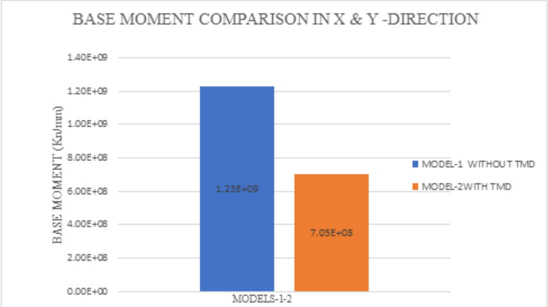


Table 7 Base Moment(Kn/mm) comparison in x&y-direction

Figure 18 displays the base moment comparison of Model-1 and Model-2 in the X&y-direction. It is observed that TMD reduces base moment of Model-2 by 42% when compared to Model-1 having no TMD

B. For Model-3(Without TMD) and Model-4(With TMD)

1. Time Period

MODE NO.	MODEL-3 (WITHOUT TMD)	MODEL-4 (WITH TMD)
1	3.713	2.91
2	3.713	2.91
3	3.32	2.58
4	1.22	0.95
5	1.22	0.95
6	1.099	0.85
7	0.703	0.55
8	0.703	0.55
9	0.645	0.50
10	0.49	0.38
11	0.49	0.38
12	0.45	0.35

Table 8 Time period(seconds) comparison

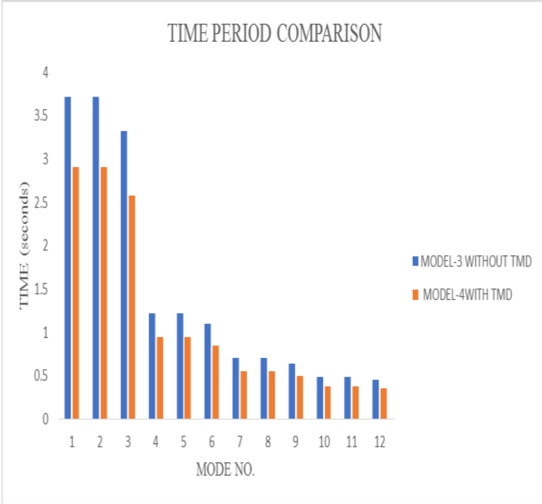


Figure 19 displays the Time period comparison of model-1 and model-2.From the figure it is seen that time period of mode-1 of model-2 having TMD is reduced by about 22% when compared to mode-1 of model-1 with no TMD.

2. Base Shear in x & y direction

	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
Base Shear	67170	41300

Table 9 Base shear(Kn) comparison in x&y-direction

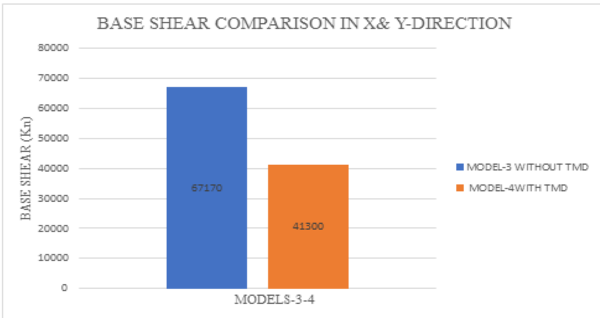


Figure 20 displays the base shear comparison of Model-1 and Model-2 in the direction. It is observed that TMD reduces base shear of Model-2 by 38.5% when compared to Model-1 having no TMD

3. Base Moment in x & y direction

	MODEL-1 (WITHOUT TMD)	MODEL-2 (WITH TMD)
Base Moment	9.70x10^8	6.67x10^8

Table 10 Base Moment(Kn/mm) comparison in x& Y-direction

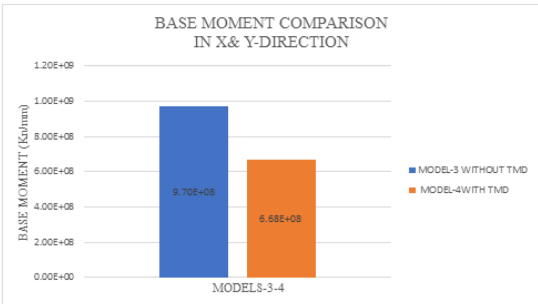


Figure 21 displays the base moment comparison of Model-1 and Model-2 in the x-y direction. It is observed that TMD reduces base moment of Model-2 by 31.3% when compared to Model-1 having no TMD

C. For Model-5(Without TMD) and Model-6(With TMD)

1. Time Period

MODE NO.	MODEL-5 (WITHOUT TMD)	MODEL-6 (WITH TMD)
1	6.25	5.17
2	6.25	5.17
3	5.38	4.18
4	2.04	1.68
5	2.04	1.68
6	1.78	1.38
7	1.16	0.95
8	1.16	0.95
9	1.05	0.82
10	0.815	0.66
11	0.815	0.66
12	0.746	0.57

Table 11 Time period(seconds) comparison

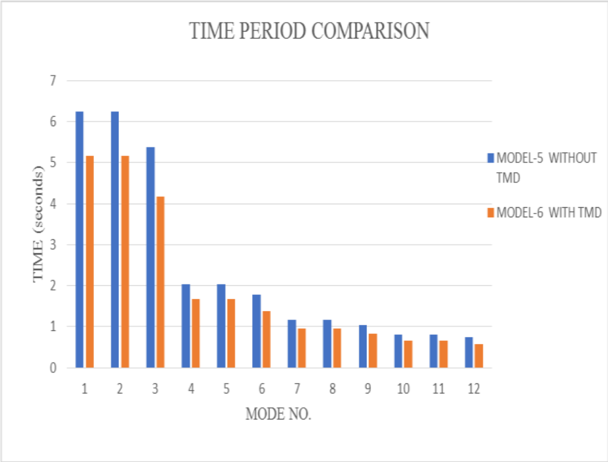


Figure 22 displays the Time period comparison of Model-1 and Model- 2.From the figure it is seen that time period of mode-1 of Model-2 having TMD reduced by about 17.3% when compared to mode-1 of Model-1 with no TMD.

2. Base Shear in x & y direction

	MODEL-5 (WITHOUT TMD)	MODEL-6 (WITH TMD)
Base Shear	89990	44680

Table 12 Base shear(Kn) comparison in x&y-direction

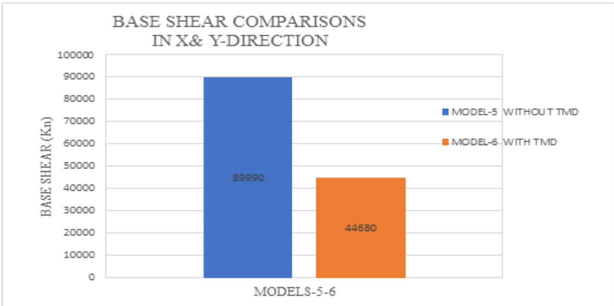


Figure 23 displays the base shear comparisons of Model-1 and Model-2 in the x-y direction. It is observed that TMD reduces base shear of Model-2 by 50.4% when compared to Model-1 having no TMD.

3. Base Moment in x & y direction

	MODEL-5 (WITHOUT TMD)	MODEL-6 (WITH TMD)
Base Moment	1.299x10^9	6.702x10^8

Table 13 Base Moment(Kn/mm) comparison in x& Y-direction

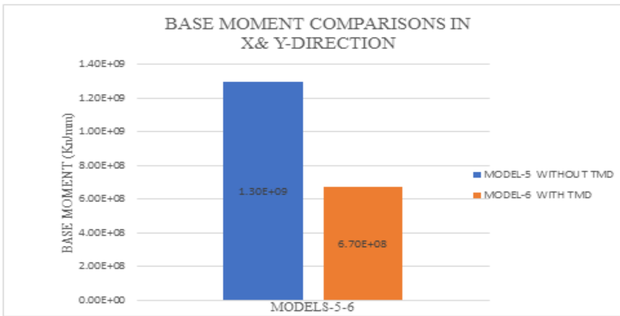


Figure 24 displays the base moment comparisons of Model-1 and Model-2 in the x & y-direction. It is observed that TMD reduces base moment of Model-2 by 48.46% when compared to Model-1 having no TMD

V CONCLUSIONS

Summary in this review suggests that the application of TMD is an appropriate to mitigate the dynamic response of the structures subjected to seismic grounded motions. From this summary following conclusion can be made:

- The overall result suggests that Tuned mass damper are great seismic control devices only for high-rise symmetric.
- In conclusion by performing NLTH Analysis, it can be demonstrated that Tuned mass damper are effective for high-rise symmetric Buildings.
- The results unfolds that, the adding of a roof-top tuned mass damper frames reducing the seismic accelerations responsible for majority of cases in spite of the fact that accelerations responses can increase if the rooftop frame is not tuned to accommodate the specific building's dynamic behavior.
- Fromanalysis, it can be seenthat it is necessary to properly implement and construct a damper in tall structures situated in earthquake prone-zones.

I. **For 15 Stories**:

- The storey displacement were decreased by 36.38% for 15-story symmetric building in both the directions under Zone V & medium soil suggesting the effectiveness of Tuned mass damper for Buildings symmetric.
- The story drift were decreased by 45.3% in both the direction compared to building with TMD and without TMD.
- The time periods were reduced by 33.02% for 15-story symmetric building with TMD compared to building without TMD.
- The base shear for building with TMD is reducing by 53% compared to building without TMD.
- The base moment for building with TMD is reduce by 42.6% compared to building without TMD.

II. **For 25 Stories**:

- The story displacement were decreased by 22.7 % for TWENTY FIVE story symmetric building under Zone V & medium soil suggesting the effectiveness of Tuned mass damper for Buildings symmetric.
- The story drift were decreased by 24.4% in both the direction compared to building with TMD and without TMD.
- The time periods were reduced by 22% for TWENTY-FIVE story symmetric building with TMD compared to building without TMD.
- The base shear for building with TMD is reduced by 38.5% compared to building without TMD.
- The base moment for building with TMD is reduced by 31.3% compared to building without TMD

III. **For 40 Stories**:

- The story displacement were decreased by 50.6 % for forty story symmetric building under Zone V & medium soil suggesting the effectiveness of Tuned mass damper for Buildings symmetric.
- The story drift were decreased by 38.26% in both the direction compared to building with TMD and without TMD.
- The time periods were reduced by 17.3% for forty story symmetric building with TMD compared to building without TMD.
- The base shear for building with TMD is reducing by 50.4% compared to building without TMD.
- The base moment for building with TMD is reduce by 48.46% compared to building without TMD.

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