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ANALYTICAL COMPARISON OF A G+8 STORY RESIDENTIAL BUILDING WITH TUNED MASS DAMPER AND PARTICLE TUNED MASS DAMPER

Sanket Shivastava[1], Dushyant Sahu[2]

[1]*M.Tech (Structural Engineering) Student, Department of Civil Engineering, GEC Jagdalpur 494001, C.G, India*
[2]*Assistant Professor, Department of Civil Engineering, GEC Jagdalpur 494001, C.G, India*

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Abstract - *Recently many taller structures have been built due to less space availability and it is economical. People also prefer living there due to security reasons. But the structures have very less damping value; it may fail easily due to any vibration induced by earthquake and wind. Many techniques have been developed to reduce the vibration of structure, out of them TMD and PTMD are ones. This paper investigates the dynamic behavior of structures with a particle tuned mass damper (PTMD) and a tuned mass damper (TMD). To identify the behavior of frame elements in the structure, Time history analysis is performed using ETABS 2016 ULTIMATE 16.2.0 software. The influence of parameters including seismic waves, damping ratios, mass ratios, and wind angles of attack are analyzed. A systematic comparison between the PTMD and TMD shows that the vibration control effects of the PTMD are generally better than those of the TMD under both earthquake and wind loads. The main reason of this is that PTMD dissipate the energy not only by tuning of frequency but it also reduces the energy by impact and friction between particles and the wall of the container. From comparison it is also clear that PTMD is better in decreasing the overturning moment as compared to TMD. An example is given to illustrate the design procedure. Comparative study is also done by keeping the values of stiffness and damping values constant for TMD and PTMD and is tuned to the structural frequency of the structure.*

***Key Words*: Particle Tuned Mass Damper, Tuned Mass Damper, Time History Analysis, Story Displacement, Overturning Moment, Base Shear**

1. INTRODUCTION

Earthquake resistant structures are structures designed to protect building from earthquake. While no structure can be entirely immune to damage from earthquakes, the goal of earthquake-resistant construction is to erect structures that fare better during seismic activity than their conventional counterparts. According to building codes, earthquake-resistant structures are intended to withstand the largest earthquake of a certain probability that is likely to occur at their location. This means the loss of life should be minimized by preventing collapse of the buildings for rare earthquakes while the loss of the functionality should be limited for more frequent ones.

The numbers of high rise buildings are increasing continuously as they provide more housing in less space. The structures should be designed considering dynamic forces through a combination of strength, flexibility and energy absorption such that it may deform above elastic limit when subjected to earthquake motions. Various techniques have been adopted to make structures free from earthquake and structural vibration caused due to wind load. Techniques are classified as follows: (i) Active control, (ii) Passive control, (iii) Semi-active control and (iv) Hybrid control.

1.1 Tuned Mass Damper

A Tuned Mass Damper (TMD) also known as seismic damper is a device which is used in structure to reduce the amplitude of the vibrations caused by earthquake or any other medium. It is a Passive control device which mainly consists of a mass, a spring, and a damper that is attached to structure to reduce the dynamic response of structure. Energy is dissipated or overcome by the inertial force of damper which acts on structure in opposite direction to force causing motion/vibration.

1.2 Particle Tuned Mass Damper

It is a passive control device which has many applications in machinery and aviation because of its good durability, high reliability and insensitivity to temperature variation. It also has great effectiveness over a large frequency range. In TMD only a single larger mass is used while in particle damping multiple auxiliary masses of small sizes are used. The Principle of PTMD comes out to removal of energy through free movement of particles within the boundaries of cavity which is attached to the primary system. PTMD are highly nonlinear dampers which dissipates energy with combination of loss mechanism, which includes friction and momentum exchange. Particle Tuned Mass Dampers has abilities to perform in wide range of frequencies and temperature. PTMD is also considered as a variety of TMD where the concentrated mass is divided into several discrete particles.

2. OBJECTIVES OF STUDY

The work has been undertaken with the following objectives:

- To study the comparison of performance of Pendulum tuned mass damper and Particle mass damper using published work as a reference and understand the behavioral aspects.

- To review the literature, covering various types of tuned mass dampers and the behavior of structures constructed with tuned mass damper.
- To review the literature, covering various types of particle mass dampers and the behavior of structures constructed with particle mass damper.
- To develop a simplified model of a multi story building with identical parameters and simultaneously providing it with particle mass damper and tuned mass damper.
- To carry out dynamic seismic analysis on the modeled buildings using scaled records of acceleration time histories and comparing their results.
- To study the comparative response of identical conventional and (G+8) storied with tuned mass dampers and particle mass damper buildings for high intensity earthquakes and comment on feasibility of using particle damper and tuned mass damper for highly seismic areas.

3. METHOD OF ANALYSIS

Different method of analysis has been developed with different degree of accuracy. The analysis processes are classified on the basis of three factors: the type of the externally applied loads, the behavior of structure or structural materials, and type of structural model selected. Based on the type of external action and behavior of structure, the analysis can be further classified as given below:

1. Linear static analysis
   1.1. Equivalent static method

2. Linear dynamic analysis
   2.1. Response spectrum method
   2.2. Elastic time history method

3. Nonlinear static analysis
   3.1. Push over analysis

4. Nonlinear dynamic analysis
   4.1. Inelastic time history method

Linear Static Analysis can be performed for structure having limited height and simple dimension. Linear Dynamic Analysis can be performed using two ways either Response Spectrum Method or Elastic Time History Method. This analysis will produce the higher modes of vibration and actual distribution of forces in the elastic range in a better way. With an improvement over the linear static or dynamic analysis a new analysis method is developed i.e. Nonlinear Static Analysis, in the sense that it allows the inelastic behavior of the structure. Actual behavior of the structure during an earthquake can be analyzed only by using inelastic time history analysis. Among all this methods we have used Time history method for analysis.

4. MATERIAL PROPERTIES & SPECIFICATIONS

Table -4.1: Specification

S. No.	Specifications		Size
1	Plan Dimensions (X× Y)		21.2 m × 28.4 m
2	Floor to Floor Height (Z)		3.5 m
3	Total Height of Building (G+ 8)		31.5 m
4	Type of Structure		SMRF
5	Soil Type (as per IS: 1893 (Part-1) – 2002)		Medium
6	Response Reduction Factor		5
7	Importance Factor		1
8	Seismic Zone Factor		0.36 (Zone V)
9	Grade of Concrete & Steel		M 25 & Fe 415
10	Beam Size		0.30 m × 0.50 m
11	Column Size		0.30 m × 0.60 m
12	Slab Thickness		0.150 m
13	Wall Thickness		0.200 m
14	Staircase	Rise	0.140 m
		Thread	0.300 m
		Width	1.5 m
		Stringer	0.150 m
15	Load Combination		According to IS : 1893 (Part 1) :2002
16	Loads Applied	Dead Load	Calculated as per Self Weight
		Floor Finish	1 KN/m^2
		Live Load	3 KN/m^2
		Seismic Load	Calculated as per IS: 1893 (Part-1) – 2002

5. CALCULATION

Using Time History Method following calculations has been done:

5.1 Tuned Mass Damper

Mode 1: optimum location node 9

m_d = 112.5 tone ω_d = 6.524 rad/sec

k_d = 4788.3 KN/m c_d = 161.47 KN-s /m

Mode 2: optimum location node 3

m_d = 112.58 tone ω_d = 18.68 rad/sec

k_d = 39270.5 KN/m c_d = 508.93 KN-s /m

Mode 3: optimum location node 9

m_d = 114.192 tone ω_d = 29.1 rad/sec

k_d = 96699 KN/m c_d = 864 KN-s /m

Mode 4: optimum location node 4

m_d = 114.36 tone ω_d = 37.14 rad/sec

k_d = 157737 KN/m c_d = 1172.3 KN-s /m

5.2 Particle Tuned Mass Damper

$$T = 2\pi\sqrt{\frac{L}{g}}$$

L = 1.05 m D = 0.05 m

l = 1 m

$$V_{spd} = {}^{1}/_{6}\, N\Pi D_p^3$$

$$V_{spd} = {}^{1}/_{6}\, 7\Pi(0.05)^3 = 4.58 \times 10^{-4}\ m^3$$

d = 1.64 × 0.05 = 0.082 m

Total length of container in x direction = D + d

= 0.05 + 0.082 = 0.132 m

$k_c = (0.314)^2 \times 0.1 = 6.5 \times 10^{-8}$ KN/m

$c_c = 2 \times 0.1 \times 0.05 \times 0.314 = 0.00317$ KN/m

$k_p = \omega_p^2\, m_p = (6.524)^2 \times 112.5 = 4788.3$ KN/m

$c_p = 2\, m_p\, \xi_p \omega_p = 2 \times 112.5 \times 0.11 \times 6.524$

$= 161.47$ KN/m

5. MODELING AND ANALYSIS

5.1 Plan of Building

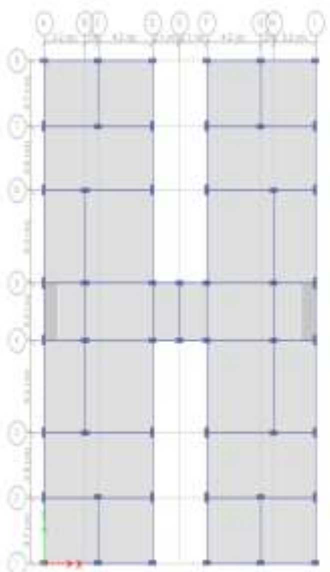

Fig -5.1: Plan of Building

5.2 Isometric View of Building

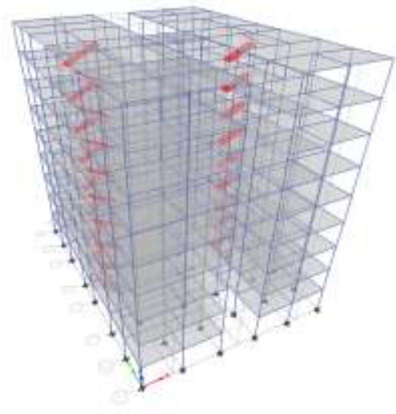

Fig -5.2: Isometric View of Building

5.3 Setup View of Tuned Mass Damper

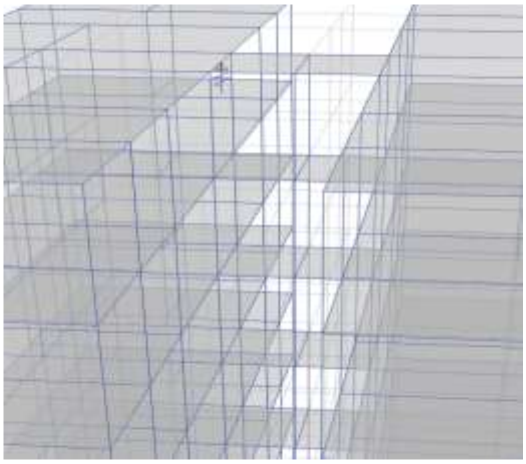

Fig -5.3: Setup view of TMD

5.4 Setup View of Particle Tuned Mass Damper

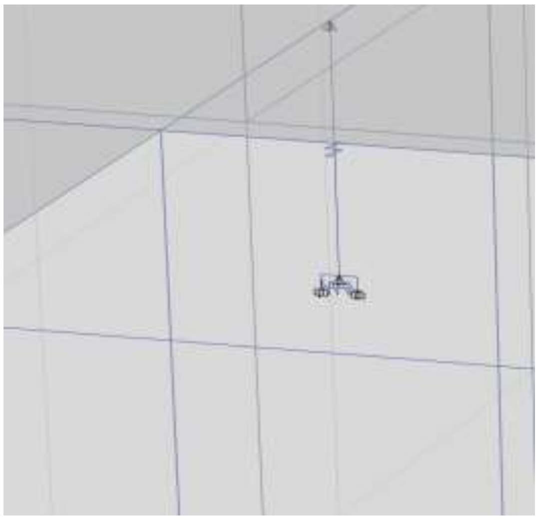

Fig -5.4: Setup view of PTMD

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6. RESULTS

6.1 Story Displacement

Displacement of different stories were determined using Time History Analysis in x and y direction for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table -6.1: Displacement from time history analysis in x direction due to EX

Story	Elevation	Without Damper	With TMD	With PTMD
	m	mm	mm	mm
Story 9	31.5	152.812	4.185	4.182
Story 8	28	144.302	10.903	10.896
Story 7	24.5	131.508	16.428	16.42
Story 6	21	115.19	18.699	18.692
Story 5	17.5	96.331	18.247	18.241
Story 4	14	75.85	15.83	15.825
Story 3	10.5	54.556	12.121	12.118
Story 2	7	33.216	7.689	7.687
Story 1	3.5	13.111	3.121	3.12

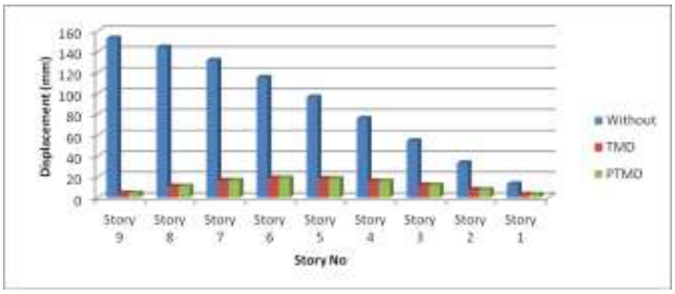

Fig -6.1: Story displacement in x direction due to EX

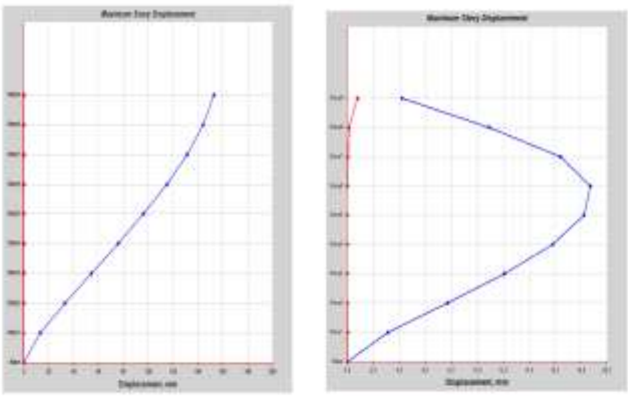

Fig -6.2: Displacement graph of structure in x direction (i) without damper (ii) with PTMD

Table -6.2: Displacement from time history analysis in y direction due to EY

Story	Elevation	Without Damper	With TMD	With PTMD
	m	mm	mm	mm
Story 9	31.5	175.089	38.969	38.968
Story 8	28	166.845	43.391	43.39
Story 7	24.5	153.213	45.422	45.422
Story 6	21	135.19	43.791	43.79
Story 5	17.5	113.961	39.131	39.13
Story 4	14	90.592	32.299	32.299
Story 3	10.5	65.99	24.067	24.067
Story 2	7	40.953	15.094	15.094
Story 1	3.5	16.698	6.139	6.139

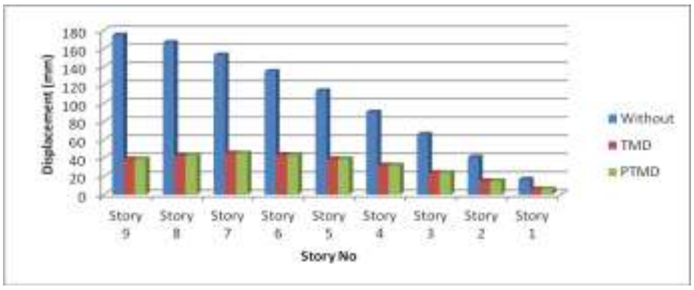

Fig -6.3: Story displacement in y direction due to EY

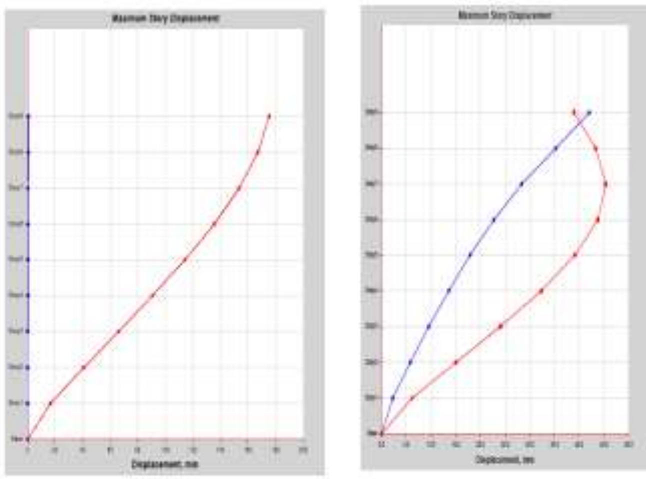

Fig -6.4: Displacement graph of structure in y direction (i) without damper (ii) with PTMD

6.2 Overturning Moment

Overturning Moments of different stories were determined using Time History Analysis for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 6.3: Overturning Moments of building from time history analysis

Story	Elevation	Without Damper	With TMD	With PTMD
	m	KN-m	KN-m	KN-m
Story 9	31.5	-0.0062	-0.0013	0.0013
Story 8	28	-0.4591	-0.0186	0.0186
Story 7	24.5	-1.4413	-0.1553	0.1553
Story 6	21	-2.9182	-0.4053	0.4053
Story 5	17.5	-4.841	-0.7589	0.7589
Story 4	14	-7.148	-1.2027	1.2027
Story 3	10.5	-9.767	-1.7203	1.7203
Story 2	7	-12.6171	-2.2931	2.2931
Story 1	3.5	-15.6119	-2.9005	2.9005
Base	0	-18.665	-3.522	3.522

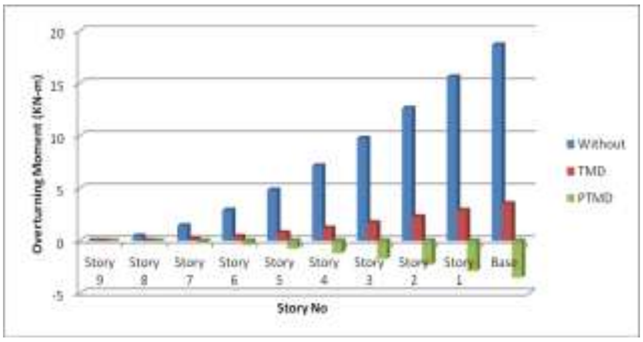

Fig -6.5: Story overturning moments

6.3 Story Shear

Shear of different stories were determined using Time History Analysis for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 6.4: Shear from time history analysis

Story	Elevation	Without Damper	With TMD	With PTMD
	m	KN	KN	KN
Story 9	31.5	0.1271	0.0045	0.0045
Story 8	28	0.2784	0.0386	0.0386
Story 7	24.5	0.4198	0.071	0.071
Story 6	21	0.5474	0.1006	0.1006
Story 5	17.5	0.6574	0.1264	0.1264
Story 4	14	0.7468	0.1476	0.1476
Story 3	10.5	0.8132	0.1634	0.1634
Story 2	7	0.8551	0.1734	0.1734
Story 1	3.5	0.8723	0.1776	0.1776

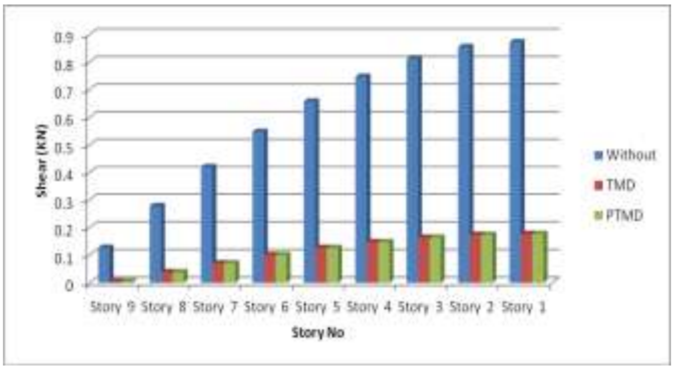

Fig -6.6: Story Shear

6.4 Base Shear

Base Shear of building were determined using Time History Analysis in x and y direction for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 6.5: Base Shear from time history analysis in x and y direction

Direction	Without Damper	With TMD	With PTMD
	KN	KN	KN
x	1910.5469	3886.0472	3884.1554
y	1528.2954	4599.3501	4598.0639

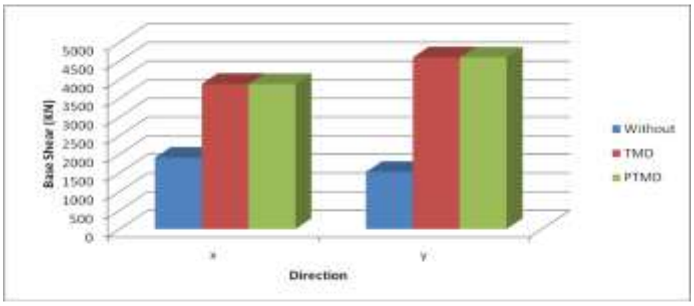

Fig -6.7: Base Shear in x and y direction

6.5 Story Stiffness

Stiffness of different stories were determined using Time History Analysis in x and y direction for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 6.6: Stiffness from time history analysis in x direction

Story	Elevation	Without Damper	With TMD	With PTMD
	m	KN/m	KN/m	KN/m
Story 9	31.5	240995.18	518843.10	518842.53
Story 8	28	317155.63	396085.35	396083.75
Story 7	24.5	342317.44	314437.62	314439.53
Story 6	21	355858.73	868037.39	868236.58
Story 5	17.5	365829.94	478231.48	478240.19
Story 4	14	375333.55	444113.47	444117.08
Story 3	10.5	387473.34	433640.20	433642.23
Story 2	7	415975.90	445882.23	445883.43
Story 1	3.5	647804.25	670830.21	670831.10

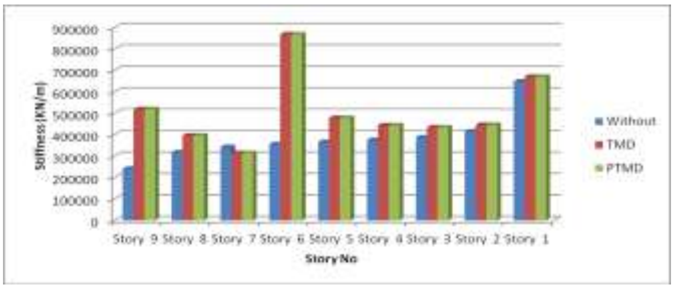

Fig -6.8: Story Stiffness in x direction

Table 6.7: Stiffness from time history analysis in y direction

Story	Elevation	Without Damper	With TMD	With PTMD
	m	KN/m	KN/m	KN/m
Story 9	31.5	282103.52	512911.74	512911.47
Story 8	28	337513.78	441115.77	441115.44
Story 7	24.5	351521.90	255294.89	255295.86
Story 6	21	358418.95	278552.29	278548.54
Story 5	17.5	363361.88	399469.08	399469.34
Story 4	14	368051.97	395322.62	395322.77
Story 3	10.5	374265.11	393893.07	393893.17
Story 2	7	391896.99	404991.35	404991.41
Story 1	3.5	573233.73	584267.81	584267.85

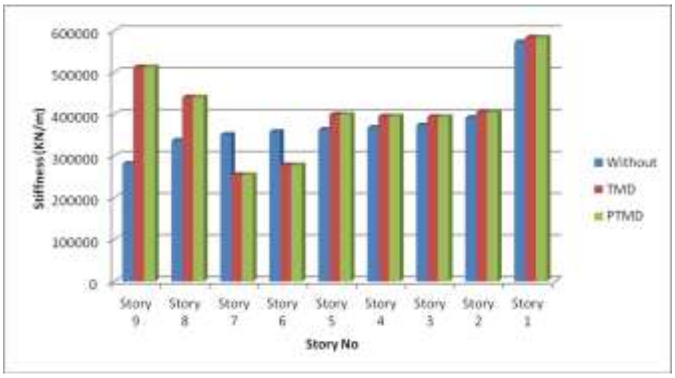

Fig -6.9: Story Stiffness in y direction

6.6 Story Drift

Drift of different stories were determined using Time History Analysis in x and y direction for building without damper, building with tuned mass damper and building with particle tuned mass damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 6.8: Drift from time history analysis in x direction due to EX

Story	Elevation m	Without Damper	With TMD	With PTMD
Story 9	31.5	0.002434	0.0027	0.0027
Story 8	28	0.003656	0.001654	0.001654
Story 7	24.5	0.004662	0.000661	0.000661
Story 6	21	0.005388	0.000129	0.000129
Story 5	17.5	0.005852	0.000691	0.000691
Story 4	14	0.006084	0.00106	0.00106
Story 3	10.5	0.006105	0.001268	0.001268
Story 2	7	0.005793	0.001317	0.001317
Story 1	3.5	0.003746	0.000892	0.000892

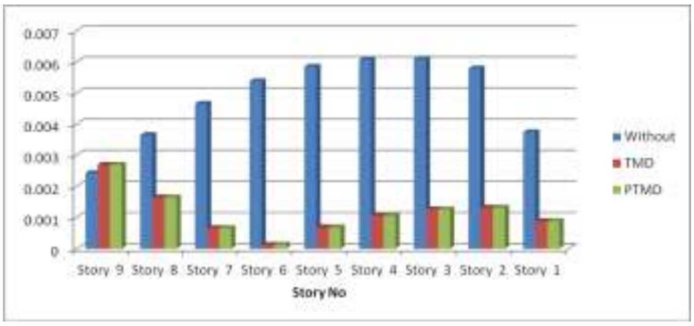

Fig -6.10: Story Drift in x direction

Table 6.9: Drift from time history analysis in y direction due to EX

Story	Elevation m	Without Damper	With TMD	With PTMD
Story 9	31.5	0.002364	0.003752	0.003752
Story 8	28	0.003895	0.002355	0.002355
Story 7	24.5	0.005149	0.001234	0.001234
Story 6	21	0.006065	0.001331	0.001331
Story 5	17.5	0.006677	0.001952	0.001952
Story 4	14	0.007029	0.002352	0.002352
Story 3	10.5	0.007153	0.002564	0.002564
Story 2	7	0.006937	0.00256	0.00256
Story 1	3.5	0.004771	0.001754	0.001754

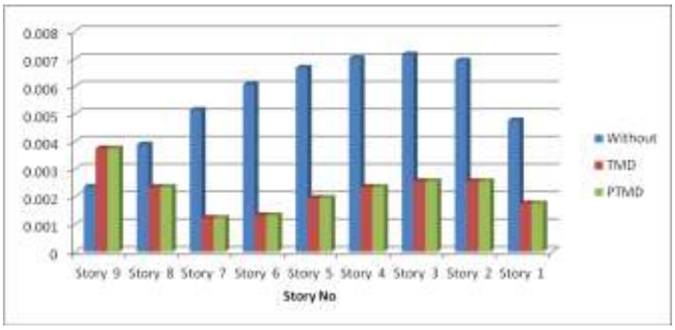

Fig -6.11: Story Drift in y direction

7. CONCLUSIONS

1. Analytical study has been done on a building by applying Tuned Mass Damper and Particle Tuned Mass Damper separately, it has seen that both are comparatively same in reduction of story displacement but there is slightly better result in Particle Tuned Mass Damper.
2. There is also an advantage of using PTMD i.e. instead of using a huge mass, multiple small particles can be used, which will decrease the area consumed by the damper.
3. In both PTMD and TMD, the response reduction is maximum near the point of installation of dampers.
4. The vibration effects of the model with an optimal PTMD or TMD were comparatively same. However, PTMD is more preferable in practical structure due to its small swing amplitude and less sensitivity to changing parameters.
5. From this study, it can be concluded that PTMD is more effective as compared to TMD and it will also occupy less space.
6. Stiffness near the application of damper increases quite high as compared to other stories.
7. From this study, it is clear that major advantage of PTMD is that, it is double effective in decreasing the overturning moment as compared to TMD.
8. Story drifts decreases with the application of dampers and result to more stable structure.
9. Story Shear with the dampers is comparatively less as compared to without damper in every floor.

8. FUTURE SCOPE

1. The study can also be done by using PTMD at different stories, small masses can be fixed at different stories which may result in reduction of response at every story.
2. A linear model is considered in the analysis. This can be analyzed by considering a non-linear model.
3. A study can be done by applying both TMD and PTMD simultaneously at a structure.
4. In current study damper is placed at the story where Eigen value is maximum, it can also be analyzed by installing dampers at other stories.

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