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SEISMIC RESPONSE OF TALL BUILDING WITH UNDERGROUND STOREY USING DAMPERS

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ABSTRACT

As the seismic load acting on a structure is a function of the self-weight of the structure, these structures are made comparatively light and flexible, which have relatively low natural damping. Results make the structures more vibration prone. New generation high rise building is equipped with an artificial damping device for vibration control through energy dissipation. A tuned mass damper is a device consisting of a mass, a spring, and a damper that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency, so 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. This research investigates the seismic response of building structures with underground stories and embedded dampers. The main response parameters are tip deflection and tip acceleration of the structure. This building has been modeled as 3D Space frame model with six degrees of freedom at each node using SAP 2000 software for simulation of behavior under gravity and seismic loading. Tuned mass dampers are considered and used for different locations of the structure. Time history method of dynamic analysis is used by SAP2000 software.

KEYWORDS: dampers, dynamic response, flexibility, frequency, spring, Time history, Tuned mass

INTRODUCTION

The most of structural system designed to carry vertical load may not have the capacity to resist lateral load or even if it has, the design of lateral load will increase the structural cost substantially with an increase in the number of storeys. The various vibration control methods include passive, active, semi-active, hybrid. Various factors that affect the selection of a particular type of vibration control device are efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety. A Tuned mass damper is a passive damping system which utilizes a secondary mass attached to a main structure normally, through spring and dashpot to reduce the dynamic response of the structure. The secondary mass system is designed to have the natural frequency, which depends on its mass and stiffness, tuned to that of the primary structure. When that particular frequency of the structure gets excited, the TMD will resonate out of phase with the structural motion and reduces its response. Then, the excess energy that is built up in the structure can be transferred to a secondary mass and is dissipated by the dashpot due to relative motion between them at a later time. The mass of the secondary system varies from 1-10% of the structural mass. As a particular earthquake contains a large number of frequency content, nowadays multiple tuned mass dampers has been used to control earthquake induced motion of high rise structure where the more than one TMD is tuned to the different unfavorable structural frequency.

TUNED MASS DAMPER

A tuned mass damper (TMD) is a device consisting of a mass, a spring, and a damper that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency so 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 Tuned Mass Damper (TMD) concept was first applied by Frahm in 1909 (Frahm, 1909) to reduce the rolling motion of the ships as well as ship hull vibrations. The natural frequency of the TMD is tuned in resonance with the fundamental mode of the primary structure, so that a large amount of the structural vibrating energy is transferred to the TMD and then dissipated by the damping as the primary structure is subjected to external disturbances. Consequently, the safety and habitability of the structure are greatly enhanced. From the field vibration measurements, it has been proved that a TMD is an effective and feasible system to use in structural vibration control against high earthquake loads.

LITERATURE REVIEW

Structural control systems increase the energy dissipation capacity of structures during an earthquake by converting mechanical energy into heat energy. Different kinds of energy dissipation systems are given below:

- **Chakraborty and Roy, 2011** comprising a mass, spring attached to the structure and are used for vibration control of structures when subjected to earthquake excitations. It is a frequency dependent device. Recently, much research has been carried out such as analytical, numerical, experimental and optimum solutions of structures to study the effectiveness of TMDs in reduction of seismic response of structures.
- **Linet Al., 1999** for seismic reduction of irregular buildings. Here, five real earthquakes were considered for numerical and statistical analysis of five storey torsion ally coupled building. Results demonstrate that PTMD effectively reduces the response on building during an earthquake.
- **Zuo Et Al., 2004** have developed a multi degree of freedom tuned mass damper. To obtain the optimal solution experiments was conducted sequentially to optimize the two degrees of freedom system. TMD can be tuned to damp the first two flexural modes of a free-free beam.
- **Pinkaew Et Al., 2003** have reported that structure with tuned mass damper was less effective for seismic damage reduction.
- **Peter, 2006** has discussed the theoretical and experimental studies on tuned mass damper for the seismic retrofitting of existing structures.
- **Almazan Et Al., 2007** have observed that new bidirectional and homogenous tuned mass dampers are very effective in reducing the seismic response of structures.
- **Marano Et Al., 2007** have proposed a linear tuned mass damper for seismic control of structures by using constrained reliability based on optimization technique.
- **Marano Et Al., 2010** have investigated the optimum parameter of tuned mass damper for minimization of displacement of the structure. From the results it was concluded that the design variable mass of the TMD considered was more capable compared to the solutions obtained without it.

METHODOLOGY

This building has been modeled as 3D Space frame model with six degrees of freedom at each node using SAP 2000 software for simulation of behavior under gravity and seismic loading. The isometric 3D view and plan of the building model is shown as figure. The support condition is considered as fully fixed

Side Soil

The side soil behavior is represented using p-y curves. P-y curves are force versus displacement functions that are generally used to model the reaction of the soil for applications involving laterally loaded piles.

Table 1: Earth Pressure Calculation

Earth Pressure	Soil		
	3m	6m	9m
Pa = KaϒH	41.6025	83.1202	124.419
Pp = KpϒH	70.092	140.327	210.932

Table 2: Pp-Pa (Side Soil, Spring Constant, K for 3m)

Pp-Pa	
Displacement (mm)	H = 3m
1.3	2.590
5.63	11.215
9.96	19.840
14.29	28.490

Table 3: Pp-Pa (Side Soil Spring Constant K for 6m)

Pp-Pa	
Displacement (mm)	H = 6m
1.3	5.200
3.467	13.868
5.634	22.535
7.801	31.203
9.968	39.871
12.135	48.539
14.302	57.207

Table 4: Pp-Pa (Side Soil Spring Constant K for 9m)

Pp-Pa	
Displacement (mm)	H = 9m
1.3	7.8637
2.744	16.6009
4.189	25.338
5.633	34.0752
7.078	42.81239
8.522	51.54956
9.966	60.28674
11.411	69.02391
12.855	77.76108
14.300	86.51277

Modeling Statement

The building considered in the present report is G+15 and G-3, G-2, G-1 deep basement storied R.C framed building of symmetrical rectangular plan configuration. Complete analysis is carried out for dead load, live load & seismic load using SAP2000. Time History method of seismic analysis is used. All combinations are Considered as per IS 1893:2002.

The typical plan of the building is shown in Figure 1

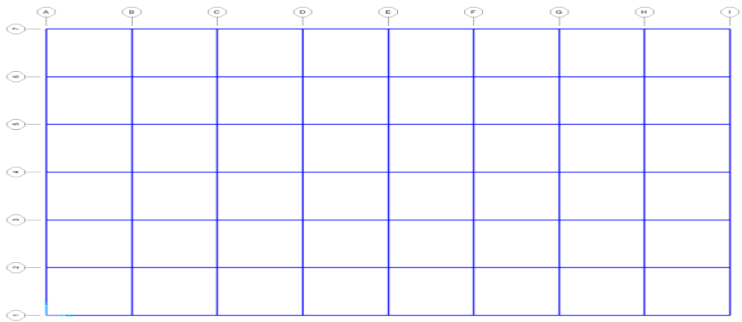

Figure 1: Plan of G+15 RCC Framed Structure

BUILDING PROPERTIES

Site Properties

Details of building: G+10 and G-3, G-2, G-1

Plan Dimension: 40m x 40m, 5m span in each direction.

Outer wall thickness: 230mm

Inner wall thickness: 230mm

Floor height: 3 m

Parking floor height: 3m

Seismic Properties

Seismic zone: IV

Zone factor: 0.24

Importance factor: 1.0

Response Reduction factor R: 5

Soil Type: medium

Material Properties

Material grades of M35 & Fe500 were used for the design.

Loading on structure

Dead load: self-weight of structure

Weight of 230mm wall: 13.8 kN/m²

Live load: For G+15:: 3.5 kN/m²

For G-3: 5 kN/m²

Roof: 1.5 kN/m²

Wind load: Not considered

Seismic load: Seismic Zone IV

Preliminary Sizes of Members

Column: 800mm x 600mm

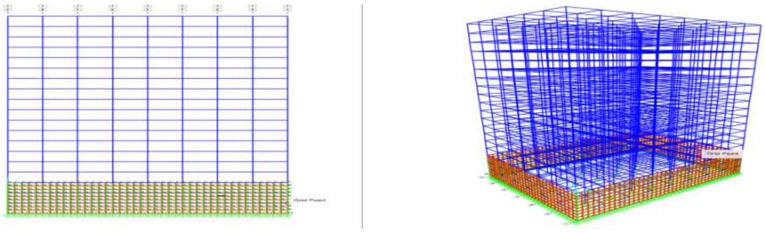

Figure 2: Elevation of G+15 RCC Framed Structure

Beam: 300mm x 600mm

Slab thickness: 125mm

Retaining wall thickness: 250mm

The models created are as follows:

Model 1: G+15 and G-3, G-2, G-1 storey bare frame building.

Model 2: G+15 and G-3, G-2, G-1 storey building with 1 dampers located at center of top of the structure.

Model 3: G+15 and G-3, G-2, G-1 storey building with 64 dampers located at corner joints of all the floors.

Model 4: G+15 and G-3, G-2, G-1 storey building with 192 dampers located at exterior joints of all the floors.

Model 5: G+15 and G-3, G-2, G-1 storey building with 208 dampers located at exterior joints and interior joints of all the floors.

Model 6: G+15 and G-3, G-2, G-1 storey building with 448 dampers located at perimeter joints of all the floors.

Model 7: G+15 and G-3, G-2, G-1 storey building with 1008 dampers located at all joints of all the floors.

Table 5: Designed Dampers Parameters for G+15, G-1 Structure

No. of Dam-Per	Mass of 1 Damp-ER (KN)	Mass of 1 Damp-ER (Kg)	Frequency of Damper $\omega d = \omega n/(1+\mu)$	Optimum Damper Ratio $\zeta opt = \sqrt{3\mu/8(1+\mu)^3}$	Stiffness of Damper in U1 Dir = AE/l	Stiffness of Damper in U2,U3 Dir = Mg/L	Time Period of Damper $Td=2\pi/\omega d$	Length of Damper L
1	26566.63125	2709042.46	2.54	0.168	369607084449.15	17427650.76	2.476	1.52
64	415.104	42328.788			369607084449.15	272307.04		
192	138.368	14109.596			369607084449.15	90769.01		
208	127.724	13024.243			369607084449.15	83786.79		
448	59.301	6046.97			369607084449.15	38901.01		
1008	26.356	2687.542			369607084449.15	17289.34		

Table 6: Designed Dampers Parameters for G+15, G-2 Structure

No. of Damper	Mass of 1 Damper (KN)	Mass of 1 Damper (Kg)	Frequency of Damper ωd =ωn/(1+μ)	Optimum Damper Ratio ζopt= √3μ/8(1+μ)³	Stiffness of Damper in U1 Dir = AE/l	Stiffness of Damper in U2,U3 Dir = mg/L	Time Period of Damper Td=2π/ωd	Length of Damper L
1	27267.31875	2780492.7	2.44	0.168	369607084449.15	16504637.01	2.578	1.65
64	426.052	43445.198			369607084449.15	257884.95		
192	142.017	14481.733			369607084449.15	85961.65		
208	131.093	13367.753			369607084449.15	79349.21		
448	60.865	6206.457			369607084449.15	36840.71		
1008	27.051	2758.425			369607084449.15	16373.65		

Table 7: Designed Dampers Parameters for G+15, G-3 Structure

No. of Damper	Mass of 1 Damper (KN)	Mass of 1 Damper (Kg)	Frequency of Damper ωd =ωn/(1+μ)	Optimum Damper Ratio ζopt = √3μ/8(1+μ)³	Stiffness of Damper in U1 Dir = AE/l	Stiffness of Damper in U2,U3 Dir = mg/L	Time Period of Damper Td=2π/ωd	Length of Damper L
1	27968.01	3E+06	2.33	0.168	369607084449.15	15446688.65	2.698	1.81
64	437	44562			369607084449.15	241354.51		
192	145.667	14854			369607084449.15	80451.50		
208	134.462	13711			369607084449.15	74262.93		
448	62.429	6365.9			369607084449.15	34479.22		
1008	27.746	2829.3			369607084449.15	15324.10		

RESULTS

Following graphs show comparative results for time history BHUJ data for different damper positions.

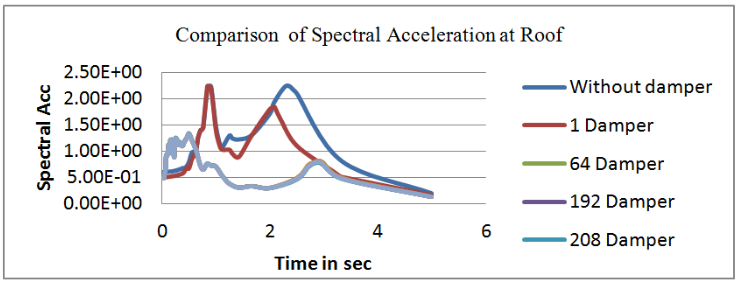

Figure 3: Comparison of Spectral Acceleration at Roof (G-1 Story)

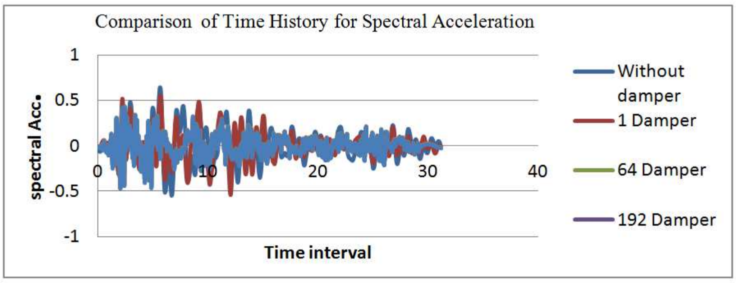

Figure 4: Comparison of Time History for Spectral Acceleration (G-1 Story)

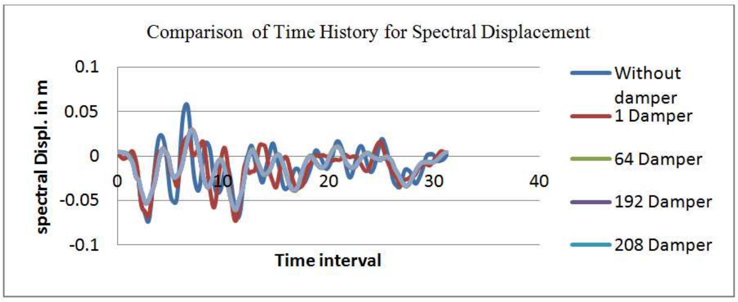

Figure 5: Comparison of Time History for Spectral Displacement (G-1 Story)

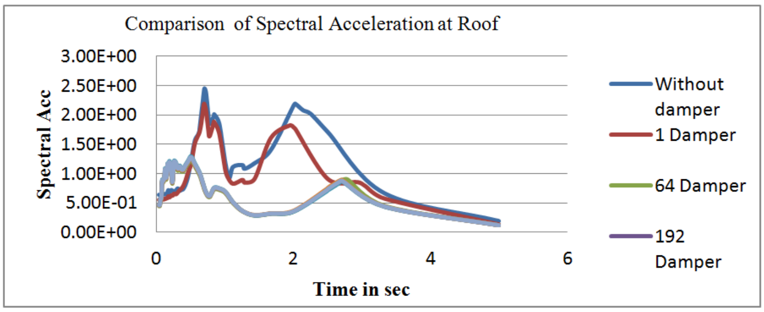

Figure 6: Comparison of Time History for Spectral Acceleration (G-2 Story)

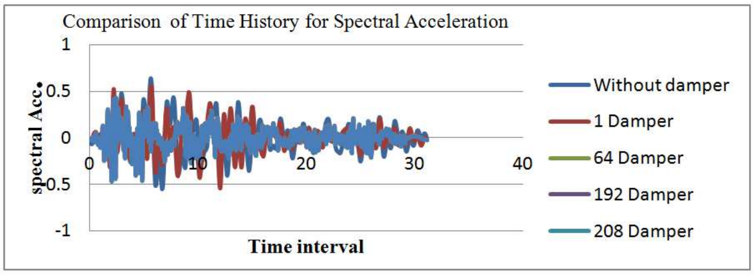

Figure 7: Comparison of Time History for Spectral Acceleration (G-2 Story)

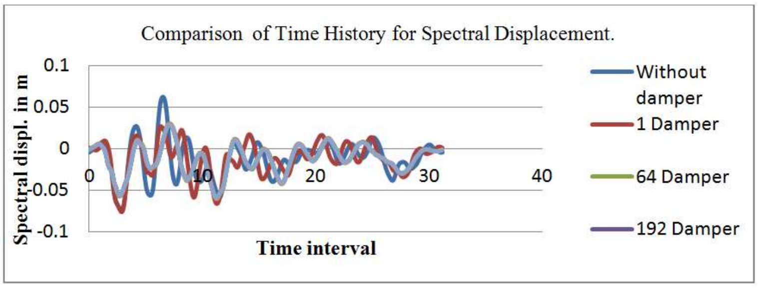

Figure 8: Comparison of Time History for Spectral Displacement (G-2 Story)

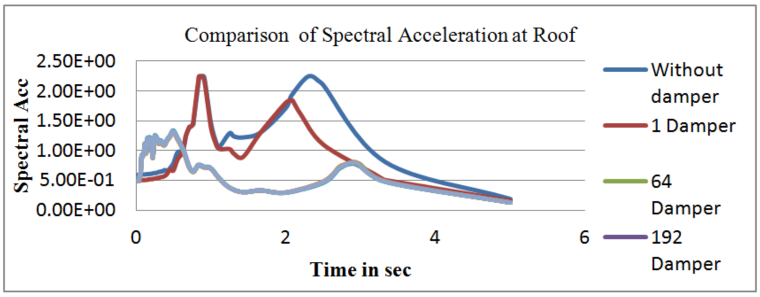

Figure 9: Comparison of Spectral Acceleration at Roof (G-3 Story)

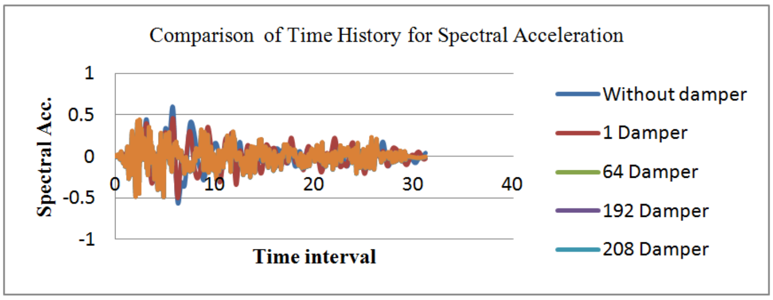

Figure 10: Comparison of Time History for Spectral Acceleration (G-3 Story)

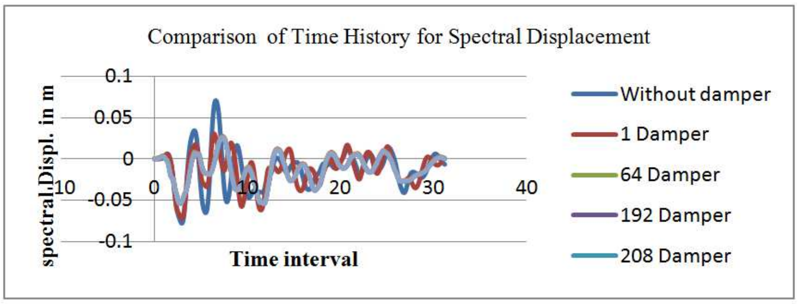

Figure 11: Comparison of Time History for Spectral Displacement (G-3 Story)

Table 8: Modal Periods

Type of Structure	Period Sec Without Damper	Period Sec 1 Damper	Period Sec 64 Damper	Period Sec 192 Damper	Period Sec 208 Damper	Period Sec 448 Damper	Period Sec 1008 Damper
G+15,G-3 structure	2.44792	3.30329	2.96015	2.95583	2.96709	2.95073	2.95669
G+15,G-2 structure	2.34153	3.24951	2.87995	2.82412	2.8335	2.82134	2.82466
G+15,G-1 structure	2.2514	3.04886	2.78754	2.71003	2.71669	2.7067	2.70923

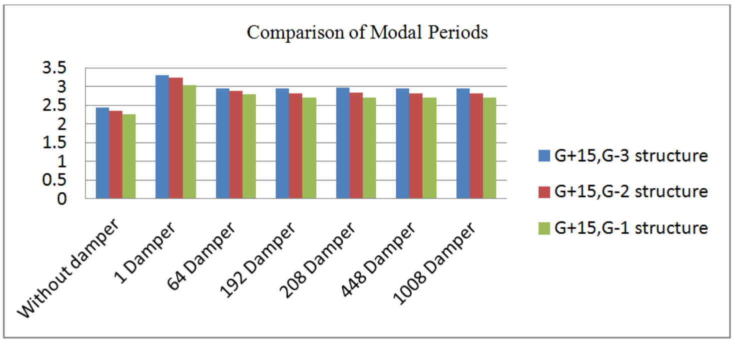

Figure 12: Comparison of Modal Periods

CONCLUSIONS

Current trends in the construction industry demands taller and lighter structures, which are also more flexible and having quite a low damping value. This increases failure possibilities and also, problems from the serviceability point of view. Several techniques are available today to minimize the vibration of the structure, out of which concept of using TMD is one among them The results of this investigation shows that, the response of structures can be dramatically reduced by using mass tuned damper without increasing the stiffness of the structure.

- It has been found that the TMDs can be successfully used to control vibration of the structure.
- Displacement is controlled with single TMD in structure. Therefore, the TMD should be placed at the top floor for best control of the first mode
- It is observed that, the acceleration can be reduced by a substantial amount whereas displacement to a considerable amount
- The analytical study on the effect of Tuned Mass Damper in high rise structures has been done. The parameters like base shear, storey displacement, joint acceleration and frequency have been compared

- The base shear of all storey buildings with Tuned Mass Dampers in all the directions is very less when compared to building with TMD in structure.
- It is observed that time history plot of base shear, acceleration and displacement is reduced for TMD and MTMD as compared to normal structure.

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