INFLUENCE OF TUNED MASS DAMPER ON BUILDING VIBRATION CONTROL DUE TO SEISMIC FORCE

A. Eswara rao[1], K. Vamsi krishna[2]

[1]*P.G.Student , Department of Civil Engineering, Swamy Vivekananda Engineering College, A.P, India.*
[2,] *Assistant Professor, Department of Civil Engineering ,Swamy Vivekananda Engineering College, India.*

ABSTRACT

The present construction is going with taller structures to provide more accommodation in less area due to an increase of population with the scarcity of land. These tall structures are constructed with flexible, low damping which causes major damage to the structure when the seismic force acts on the structure. The seismic waves caused by earthquake makes the structure to sway and oscillate in different directions. In order to reduce the vibrations of structure different approaches have been proposed, among them Tuned Mass Damper is preferable and have been widely used in practice. Analysis of a G+9 3D model with and without TMD using Sap2000 software. The tuned mass damper is placed on top of the structure to observe the response of the structure with and without TMD.

Keywords: *Tuned Mass Damper, Seismic Force, Building, Vibrations*.

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1. INTRODUCTION

The earth quake caused great disasters in the form of loss to property and human life .The seismic waves caused by an earth quake creates vibrations in buildings makes the structure to sway and oscillate in different directions depends on frequency, direction of ground motion, height of structure and type of construction. Most of the structures are designed to carry vertical load, so it may become weak during the time of earthquake. To keep the structure safely vibrations occurred due to seismic force in building should be minimized. The control of structural vibrations produced by earthquake can be done by various means such as modifying rigidities, masses, damping and by providing passive or active counter forces.

Earthquake originates below the surface of the earth due to rupture of bed-rock. This is associated with release of stored strain energy that spreads out in all directions from the fault region in the form of seismic waves. The seismic waves travel for great distances before finally losing most of their energy. At some time after their generation, these seismic waves will reach the earth’s surface, and set it in motion, which we surprisingly refer to as earthquake ground motion. When this earthquake ground motion occurs beneath a building and when it is strong enough, it sets the building in motion, starting with the buildings foundation, and transfers the motion throughout the rest of building in a very complex way. These motions in turn induce forces which can produce damage. The characteristics of the ground shaking control earthquake response of buildings, in addition to the building characteristics. The ground motion can be measures in the form of acceleration, velocity or displacement. Earth scientists are interested in capturing the size and origin of earthquakes worldwide, and measure feeble ground displacements even at great distances from the epicenter of the earthquakes. Instruments that measure these low level displacements are called Seismographs. In the vicinity of the epicenters of large earthquakes, the ground shaking is violent. Seismographs get saturated, as their design is such that they get saturated under large displacement shaking, and become ineffective in capturing the displacement of the ground. And, on the other hand, engineers are interested in studying levels of ground shaking at which buildings are damaged, and are conversant with forces (as part of the design process of building). Hence, this motivated the development of instruments called Accelerographs, that record during the earthquake shaking acceleration as a function of time of the location where the instrument is placed. These instruments successfully capture the ground shaking even in the near field of the earthquake faults, where the shaking is violent.

1.1 TYPES OF ZONES

The earth quake zoning map of India divides India into 4 seismic zones based on the observations of the affected area due to earthquake India divide into four types of zones

- Zone 2 - Least active zone
- Zone 3 - Moderate seismic zone
- Zone 4 - High seismic zone
- Zone 5 - Highest seismic zone

1.2 VIBRATION

It defined as a motion which repeats after equal interval of time and is also a periodic motion. Vibrations occurs in all bodies which are having mass and elasticity. They are caused due to several reasons such as presence of unbalanced force in rotating machines, elastic nature of system, external application of force. Vibrations are undesirable in most engineering systems and desirable in few cases.

1.3 CLASSIFICATION OF VIBRATION

One method of classifying mechanical vibrations is based on degrees of freedom. The number of degrees of freedom for a system is the number of kinematically independent variables necessary to completely describe the motion of every particle in the system. Based on degrees of freedom, we can classify vibrations as follows

a) Single degree of freedom systems
b) Two degree of freedom systems
c) Multi degree of freedom systems
d) Systems with infinite degrees of freedom

Some other important classifications are as follows

e)Free and Forced vibration
f)Damped and Undamped vibration
g)Linear and Non-linear vibration

1.4 SOURCES OF VIBRATION

1.4.1 Earthquake

The seismic waves caused by an earthquake will make buildings sway and oscillate in various ways depending on the frequency and direction of ground motion, and height and construction of the building seismic activity can cause excessive oscillations of the building which may lead to structural failure.

1.4.2 Wind

The force of wind against tall buildings can cause the top of skyscrapers to move more than a meter. This motion can be in the form of swaying and can cause the upper floors of each buildings to move. Certain angles of wind and aerodynamic properties of a building can accentuate the movement and cause motion sickness people.

1.4.3 Mechanical sources

Masses of people walking up and down stairs at once or great numbers of people stomping in unison, can cause serious problems in large structures like stadiums if those structures lack damping measures.

1.5 CONSEQUENCES OF VIBRATION

a) Damages to safety-related equipment
b) Adverse human response
c) Fatigue fracture
d) Over stressing and collapse of structures
e) Cracking and other damage

1.6 CLASSIFICATION OF SEISMIC CONTROL SYSTEMS

1.6.1 Passive control systems

All vibration structures dissipate energy due to internal stressing, rubbing, cracking, plastic deformations, and so on, the larger the energy dissipation capacity the smaller the amplitudes of vibration. Some structures have very low damping of the order of 1% of critical damping and consequently experience large amplitudes of vibration even for moderately strong earthquakes. Methods of increasing the energy dissipation capacity are very effective in reducing the amplitudes of vibration. Many different methods of increasing damping have been utilized and many others have been proposed. Passive energy dissipation systems utilities a number of materials and devices for enhancing damping, stiffness and strength, and can be used both for natural hazard mitigation and for rehabilitation of aging or damaged structures. The passive control device includes.

- Base Isolation
- Passive Energy Dissipating (PED) Devices

1.6.1(a) Base Isolation

Fig 1

a)building without base isolation during earthquake
b)building with base isolation during earthquake

If a building placed on a material which have low lateral stiffness, such as rubber then the building achieves a flexible base. During the earthquake, the flexible bases reduces the peak response from the earth quake able to filter out high frequencies from the ground motion and to protect the building from damage.

- **Low-Damping Natural or Synthetic Rubber Bearing**
  Linear behavior in shear for shear strains up to and exceeding 100%.
  Damping ratio = 2 to 3%

Advantages:

- Simple to manufacture
- Easy to model
- Response not strongly sensitive to rate of loading, history of loading, temperature, and aging.

Disadvantage:

- Need supplemental damping system
- **High-Damping Natural Rubber Bearing**
- Damping increased by adding extra-fine carbon black, oils or resins,
- and other proprietary fillers.
- Maximum shear strain = 200 to 350%.
- Damping ratio = 10 to 20% at shear strains of 100%.
- Effective Stiffness and Damping depend on:
- Elastomer and fillers
- Contact pressure
- Velocity of loading
- Load history (scragging)
- Temperature
- **Lead-Rubber Bearing (Low damping natural rubber with lead core)**
- Properties of can be improved by placing a lead core into the bearing
- Damping of the lead-plug bearing varies from 15% to 35%
- The Performance depends on the imposed lateral force
- The hysteretic damping is developed with energy absorbed by the lead core.
- Maximum shear strain = 125 to 200%

1.6.1(b) Passive Energy Dissipating Devices (PED)

- **Metallic Yield Dampers**

- Most effective mechanism for absorbing seismic energy during earth quake is through inelastic deformation of metals. The usage of metallic energy dissipaters to make structure safely during earthquake began with both theoretical and experimental work of Kelly etal. (1972) and Skinner et al. (1975). Some of the energy dissipaters like torsional beams, flexural beams and v-strip energy dissipaters used mild steel plates with triangular shapes to spread yielding uniformly throughout the material.

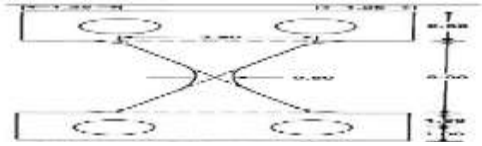


Fig 2

❖ Friction dampers:

Friction plays important role in energy dissipation and has been used for many years in automotive brakes to reduce the kinetic energy of motion. During the development of friction dampers, it is important to control stick-slip phenomena to avoid high frequency excitation. Furthermore, compatible materials must be available to maintain a consistent coefficient of friction over the intended life of the device. The Pall device is one of the damper elements utilizing the friction principle, which can be installed in a structure in an X-braced frame as illustrated in the figure (Palland Marsh 1982).

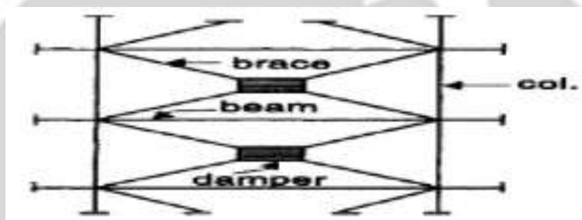


Fig 3

❖ Viscoelastic Dampers

Both metallic and frictional dissipating devices are mainly used for seismic application. But, viscoelastic dampers are useful for energy dissipating in both wind and seismic application. The usage of viscoelastic dampers are started in 1969 when approximately 10000 visco-elastic dampers were installed in each of the twin towers of the World Trade Center in New York to reduce wind-induced vibrations. Extension of study on viscoelastic dampers have been carried out and the result show that this damper is also works effectively during large intensity levels of earthquake. Materials used in viscoleastic dampers are copolymers or glassy substances.

❖ Tuned Liquid Dampers

Tuned liquid column dampers (TLCDs) are a special type of tuned liquid damper (TLD) that rely on the motion of the liquid column in a U-shaped tube to counter act the action of external forces acting on the structure. The inherent damping is introduced in the oscillating liquid column through an orifice. The performance of a single- degree-of-freedom structure with a TLD subjected to sinusoidal excitations was investigated by Sun (1991), along with its application to the suppression of wind induced vibration by Wakahara et al. (1989).Welt and modi (1989) were one of the first to suggest the usage of a TDL in buildings to reduce overall response during strong wind or earthquakes.

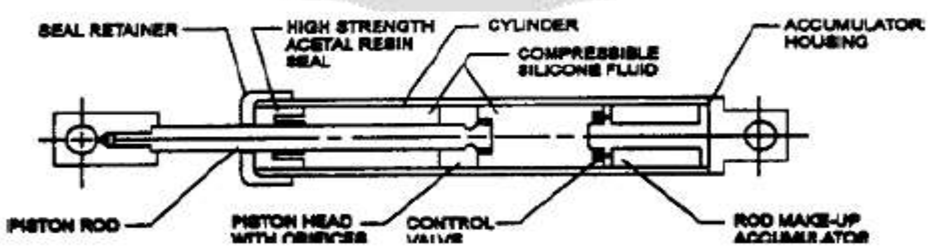


Fig 4

Tuned Mass Dampers

The concept of the tuned mass damper (TMD) dates back to the 1940s (Den Hartog 1947). It consists of a secondary mass with properly tuned spring and damping elements, providing a frequency-dependent hysteresis that increases damping in the primary structure. The success of such a system in reducing wind-excited structural vibrations is now well established). Tuned Mass Dampers (TMDs) are passive control devices that are generally installed at the tops of buildings to control the responses of buildings produced due to wind or an earthquake. Tuned Mass Damper is also known as a harmonic absorber, their application can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles, and buildings. TMD have been successfully implemented to control the responses of some well-known towers (buildings) produced by winds, such as Citicorp Tower, SydneyTower, and so on.

Active Control systems

The active control method requires an external source to activate the control system that generates a control signal to modify the structural response. Typically the control signal is generated according to a control algorithm that uses the measured response of the structure. Active control systems have been implemented for vibration control in many building in Japan. different types of sensors are placed at various locations to measure the structural response. The position of the sensors plays a very important role in control of the structural vibration in active control systems

1.7 TYPES OF ACTIVE CONTROL SYSTEMS

1. Active Mass Damper Systems -It evolved from TMDs with the introduction of an active control mechanism.
2. Active Tendon Systems – Active tendon control systems consist of a set of prestressed tendons whose tension is controlled by electro-hydraulic servomechanisms
3. Active Brace Systems

Semi-active Control Systems

It compromise between the passive and active control devices. The structural motion is utilized to develop the control actions or forces through the adjustment of its mechanical properties. The action of control forces can maintained by using small external power supply or even with battery.

1.Stiffness control devices
2. Electro-rheological dampers
3. Magnetorhelogical dampers
4. Friction control devices
5. Fluid viscous dampers
6. Tuned mass dampers
7. Tuned liquid dampers

2. METHODOLOGY

2.1 DATA REQUIRED FOR MODELLING

Height of floors : 3 m
No of bays in x and y direction 4
Seismic zone 5
Soil : Medium
Frame type : SMRF
No of storey : G+9
Slab thickness : 125mm
Beam size : 0.25mm*0.25mm
Column size : 0.3mm*0.25mm
Materials : M25 concrete, HYSD-steel
Density of concrete : 25kN/m3

2.2 PARAMETERS OF TUNED MASS DAMPER

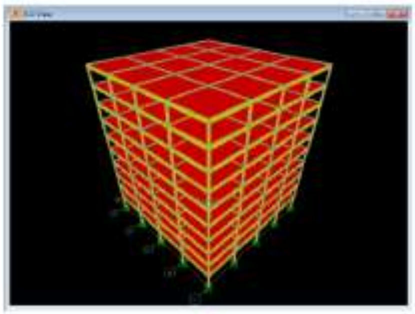
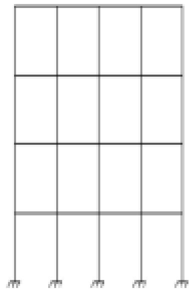
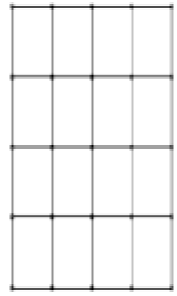
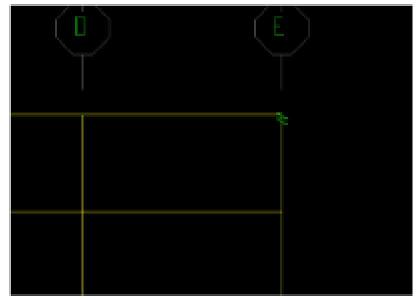
$$T_{d=} 2 \prod \sqrt{L/g}$$

$$\rightarrow \quad T_{d=} 2 \prod / \omega_d$$

$$\rightarrow \quad c_d = 2\, \varepsilon_d \sqrt{k_d m_d}$$

Td= natural time period of damper
L=length of pendulum
ωd= natural frequency of damper εd
= damping coefficient of damper

kd=stiffness of damper
md= mass of damper

FLOW CHART OF METHODOLOGY :

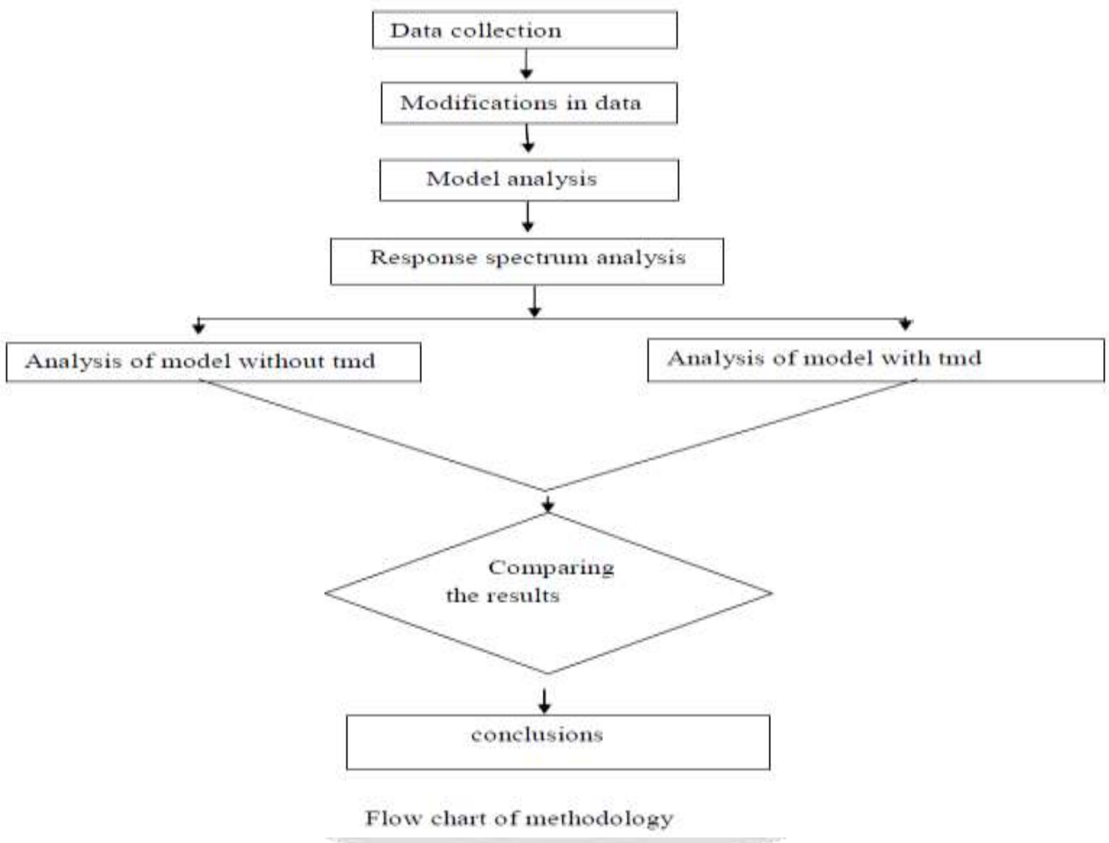


Fig : 5

2.3 MODELING APPROACH IN SAP2000

General

Sap2000 software is used to evaluate th e performance of the structure with rigid and flexible floor diaphragms using modal and response spectrum procedures.sap2000 software accepts static loads and dynamic loads and has capability of Eigen values, on linear static and dynamic analysis, linear static and dynamic analysis.

Procedure for linear dynamic analysis

a) model analysis

- Choosing the model from template
- Defining the grids
- Editing the grids
- Defining materials
- Defining frame sections

- Defining area sections
- Assigning joint restraints
- Assigning frame properties
- Assigning area sections
- Replicating slabs to all floors
- Assigning joint constraints at different level
- Run the analysis
- Displaying the results

❖ **Response spectrum for modal analysis**

- Defining live load and earthquake load
- Assigning live load
- Define functions(response spectrum)
- Defining the analysis cases
- Run analysis
- Display results

2.4 STEP WISE ANALYSIS

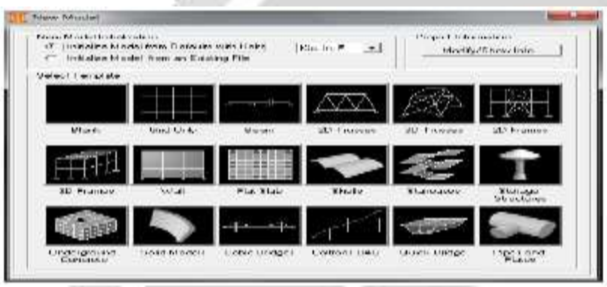


Fig :6

Fig :7

Fig : 8

Fig : 9

Fig : 10 Fig : 11

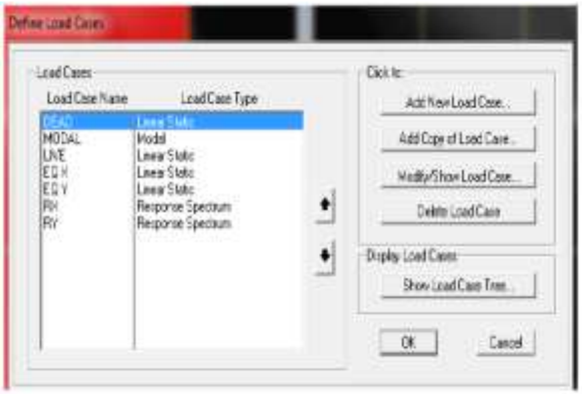
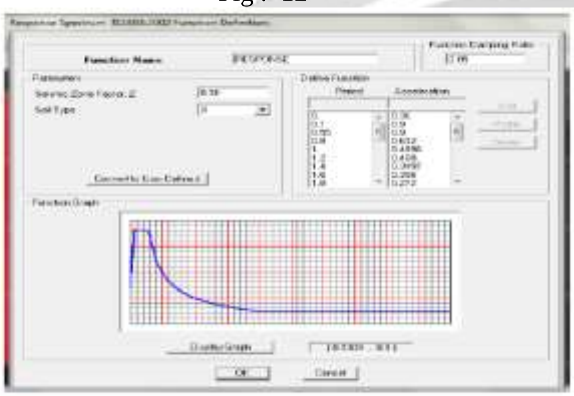


Fig : 12 Fig: 13



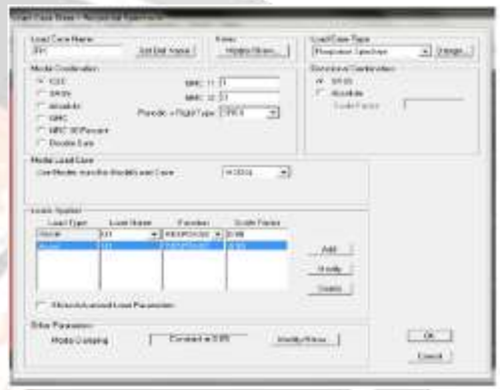


Fig : 14 Fig: 15

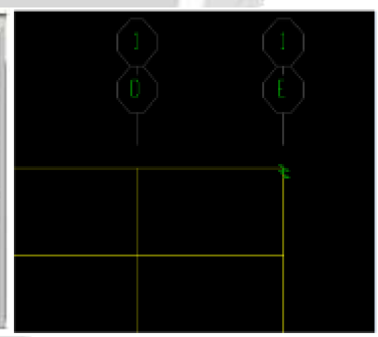


FIG: 16 FIG: 17 FIG: 18

3. RESULTS

In the present study, a three dimensional ten story is modeled in sap2000 with and without the TMD. A linear dynamic analysis is then performed on the same model for both the cases with changing mass ratios.

3.1 DISPLACEMENT

Displacement is the movement of the structural element from its original position due to some external force. To keep the structure safely, the displacement caused by that force should be minimized by placing TMD. The displacement of the diaphragm of each floor with and without TMD has detailed in table 1.

Diaphragm	Displacement without TMD (MM)	Displacement with TMD (mm)		
		3% mass ratio	6% mass ratio	9% mass ratio
1	3.2	1.2	0.8	0.6
2	7.5	2.9	1.9	1.5
3	11.6	4.5	3.0	2.4
4	15.5	6.1	4.1	3.3
5	19	7.6	5.2	4.2
6	22	9.0	6.2	5
7	24	10.3	7.1	5.8
8	26	11.4	8.0	6.6
9	28	12.4	8.8	7.3
10	28	13.1	9.5	7.9

Table 1

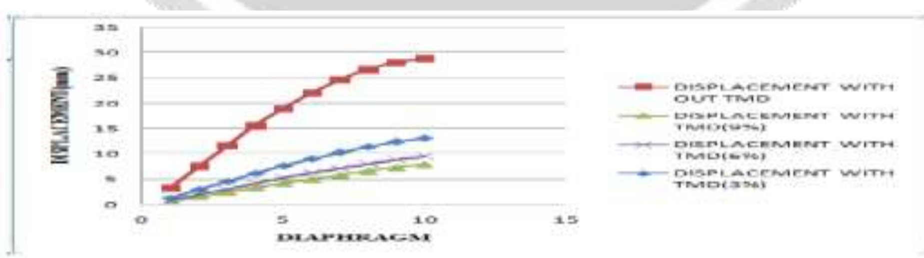


Fig: 19

Graph 1 gives information about the comparison of displacement at diaphragm of each floor of structure with and without TMD. It is clear that the maximum displacement at the 10th diaphragm of structure in first mode without TMD is 28 mm. After providing TMD with different mass ratios (3%, 6%, and 9%) displacement at 10th diaphragm of structure in first mode is reduced to (13.1 m, 9.5 mm, 7.9 mm).

3.2 ACCELERATION

Acceleration is the change of velocity at joints of a structure due to the force acting on the structure. Acceleration at diaphragm of each floor with and without TMD has detailed in table 2.

Diaphragm	Acceleration without TMD (m/sec^2)	Acceleration with TMD (m/sec^2)		
		3% mass ratio	6% mass ratio	9% mass ratio
1	0.145	0.004	0.001	0.001
2	0.333	0.009	0.004	0.002
3	0.516	0.015	0.007	0.004
4	0.688	0.020	0.009	0.005
5	0.845	0.026	0.011	0.007
6	0.982	0.030	0.014	0.008
7	1.097	0.035	0.016	0.009
8	1.185	0.039	0.018	0.011
9	1.247	0.042	0.020	0.012
10	1.280	0.044	0.021	0.013

TABLE :2

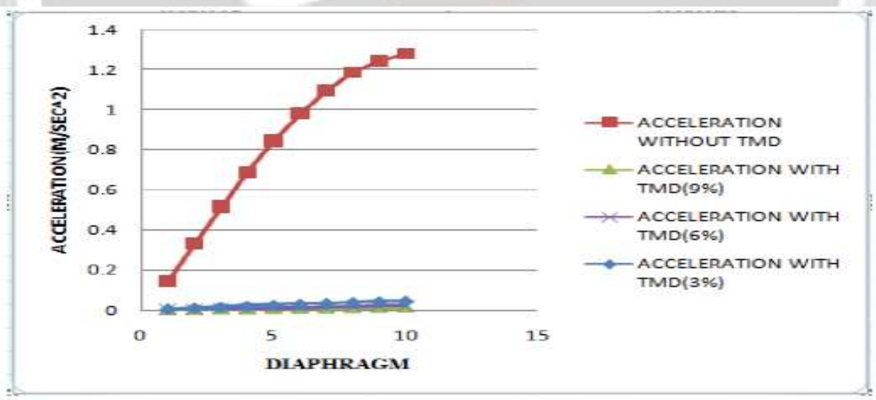


Fig : 20

Graph 2 gives information about the comparison of acceleration at diaphragms of each floor of structure with and without TMD. The maximum acceleration at diaphragm 10 of structure in first mode without TMD is 1.28 m/sec^2.After providing TMD with different mass ratios(3%,6%,9%)the maximum acceleration at diaphragm 10 of structure in first mode is reduced to(0.04m/ sec^2,0.02m/ sec^2,0.01m/ sec^2) .

3.3 FREQUENCY

The rate of oscillations occurred in one second, when the structure is vibrated due to external force is called frequency. Frequency is used to determine whether the structure is in flexible or rigid. If the oscillations are more then the structure easily tends to damage. The frequency of structure with and without TMD has detailed in Table 3

Mode Number	Frequency without TMD (rad/sec)	Frequency with TMD (rad/sec)		
		3% mass ratio	6% mass ratio	9% mass ratio
1	6.6	1.84	1.50	1.30
2	7.3	2.19	1.99	1.84
3	7.4	2.54	2.53	2.52
4	20.07	6.27	5.94	5.79
5	22.2	6.82	6.45	6.15
6	22.5	7.72	7.63	6.35
7	37.7	10.86	7.69	7.66
8	43.0	12.14	11.61	11.30
9	53.9	13.22	12.76	12.43
10	70.35	18.43	17.3	16.24

Table 3

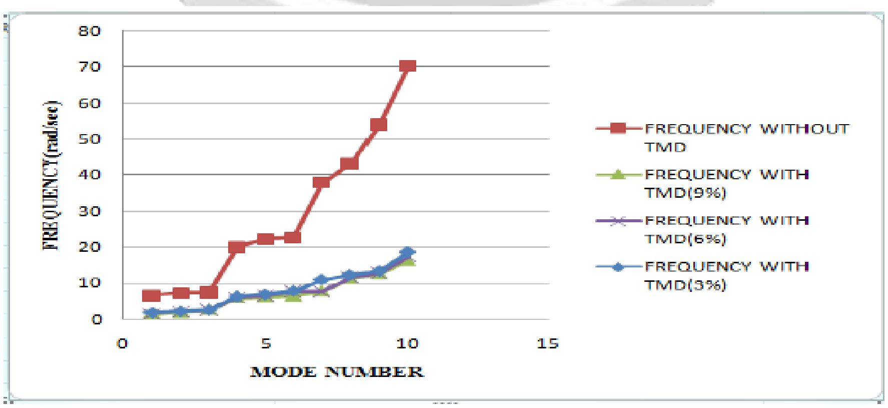


Fig -21

Graph3 gives information about the comparison of frequency of structure with and without TMD. It is clear that the frequency of structure in first mode without tuned mass damper is 6.6 rad/sec. After providing TMD with different mass ratios(3%,6%,9%) the frequency of the structure reduced to (1.84 rad/sec,1.5 rad/sec,1.3 rad/sec)

4. CONCLUSIONS

The behavior of 10 story building under linear dynamic analysis with and without TMD was analyzed in sap2000 software.TMD is more effective in controlling the displacement, acceleration, and frequency of structure under earthquake.

Content	**Top story displacement in the first mode(mm)**	**Acceleration in first mode(m/sec^2)**	**Frequency in first mode(rad/sec)**
Normal building	**28**	**1.28**	**6.6**
TMD with 3%mass ratio	**13**	**0.04**	**1.84**
TMD with 6%mass ratio	**9**	**0.02**	**1.50**
TMD with 9%mass ratio	**7**	**0.01**	**1.30**

From the Table 4 it is clear that structure with TMD reduces the response of structure. Response is more reduced with TMD of a mass ratio (9%), because the mass of the TMD mainly effects the controlling of dynamic response.

REFERENCES

[1]. PAYAL GWALANI, O. R. Jaiswal (2017) , Vibration Control using Tuned Mass Damper, International Journal of Engineering Research in Mechanical and Civil Engineering, Vol 2, Issue 3, ISSN 2456-1290.
[2]. Shilpa Chandran.P, Dr. CK Prasad Varma Thampan (2017) A Study on Vibration Control of Structures due to Seismic Excitation using Tuned Mass Damper, International Journal of Scientific & Engineering Research Volume 8, Issue 11, ISSN 2229-5518
[3]. A. Mohite, G. R. Patil. Earthquake Analysis of Tall Building with Tuned Mass Damper. IOSR Journal of Mechanical and Civil Engineering. 2015, pg 113-122.

[4]. V. Umachagi, K. Venkataramana. G. R. Reddy, R. Verma (2013). Application Of Dampers For Vibration Control Of Structures: An overview. International Journal of Research in Engineering and Technology. , Pg 6-11.

[5]. K. Muhammad, G. Lavanya(2016) Dynamic Rsistance Of Tall Buildings By Using Tuned Mass Dampers (TMD'S). International Conference on Current Research in Engineering Science and Technology, Pg 1-7.

[6] A. Sakr ((2015)Vibration control of buildings by using partial floor loads as multiple tuned mass dampers. HBRC Journal ,Pg 1-12.

[7]. H. Ibrahim, S. Aliyu and H. Hamza (2015) Vibration Control Of a Frames Structures Using Tuned Mass Damper. 2nd international conference on science and technology. Pg 873-884.

[8]. S. Kasana, S. Pal and D. Ranjan Sahoo (2015) Journal of Civil Engineering and Environmental Technology. . Pg 84-87.

[9]. Y. Tuan, G. Q. Shang. Vibration Control in a 101-Storey Building Using a Tuned Mass Damper. Journal of Applied Science and Engineering. 2014. 17(2), pg 141-156.

[10]. v.m thakur,and p.d.pachpor,(2012) seismic analysis of multi-storeyed building with tmd(tuned mass damper),international journal of engineering research and applications,vol.2,issue 1,319-326.

[11]. Agarwal P and shrikande M (2008) ”Earthquake resistance design of structures”,New Delhi,PHI Learning.

[12]. Mc namara rj (1977) tuned mass dampers for buildings.journal of the structural division,asce;103(ST9):1785-98.

[13]. Bitaraf Maryam, Ozbulut Osman E,Hurlebaus Stefan(2010) ―Application of semi-active control strategies for seismic protection of buildings with MR dampers, Engineering Structures.

[14]. Chen Genda,Wu Jingning(2001) ―Optimal placement of multiple tuned mass dampers for seismic structures‖ Journal of Structural Engineering, Vol. 127, No. 9

[15]. Chouw Nawawi(2004) ―Behaviour of soil-structure system with tuned mass dampers during near-source earthquakes‖. Thirteenth world conference on Earthquake Engineering paper no.1353

[16]. Garg Devendra P, Anderson Gary L(2003) ―Structural vibration suppression via active/passive techniques‖ Journal of Sound and Vibration 262 pp 739-751.

[17]. Ghosh A, Basu B(2004) ―Effect of soil interaction on the performance of tuned mass dampers for seismic applications ‖ Journal of Sound and Vibration 274 pp 1079–1090.

[18]. Guo Y.Q, Chen W.Q(2007) ―Dynamic analysis of space structures with multiple tuned mass dampers ‖ Engineering Structures 29 ,pp3390–3403.

[19]. Li Hua-Jun, Hu Sau-Lon James(2002) ―Tuned Mass Damper Design for Optimally Minimizing Fatigue Damage‖ Journal of Engineering Mechanics, Vol. 128, No. 6.

[20]. Pinkaew T, Lukkunaprasit P, Chatupote P(2003) ―Seismic effectiveness of tuned mass dampers for damage reduction of structures‖ Engineering Structures 25,pp39-46.

[21]. Runlin Yang, Xiyuan Zhou, Xihui Liu(2002) ―Seismic structural control using semi-active tuned mass dampers‖ Earthquake engineering and engineering vibration.

[22]. Lee Chien-Liang, ChenYung-Tsang(2006) ―Optimal design theories and applications of tuned mass dampers‖. Engineering Structures 28 pp 43–53.

[23]. Lin Chi-Chang, Lu Lyan-Ywan, Lin Ging-Long(2010) ―Vibration control of seismic structures using semiactive friction multiple tuned mass dampers‖ Engineering Structures.

IS Codes

[24]. IS:875-1987,Indian standard code of practice for design loads(other than earthquake)for Buildings and Structures,Bureau of Indian Standards,New Delhi.

[25]. IS:1893(part 1)-2002,Indian standard criteria for earthquake resistant design of structures,part 1 general provisions and buildings,Bureau of Indian Standards,New Delhi.