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Seismic Analysis of L Shaped RC Building Using Tuned Mass Damper

[1]Anmol Gupta [2]Dr. J N Vyas
[1]PG Student [2]Professor
[1,2]Department of Civil Engineering
[1,2]Mahakal Institute of Technology and Management, Ujjain, India

Abstract— Concrete is a composite material composed mainly of water, aggregate, and cement. Usually there are additives and reinforcements included to achieve the desired physical properties of the finished material. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application. The reuse of material can reduce the normal usage of ingredients in concrete and thereby reduce the cost of construction. This study is focused on the use of thermo setting plastics as a partial replacement of aggregates in concrete. The aim was to investigate the characteristics of concrete with the addition of plastic and comparing it with the control mix, thereby determining the advantages and disadvantages of doing so. One of the methods for manufacturing of such concrete involves reduction of amount of cement in the mix, which added to the reduction the total cement consumption. The use of waste materials also solves the problem of disposing the excessive amount of industrial wastes. Such Concrete is a concrete in which one or more of its constituents are replaced by a resource saving material, which ultimately has reduced environmental impacts in terms of both, resource utilization and pollution impacts together. This paper discusses the importance of such Concrete in the present day context and highlights its merits over conventional concrete which otherwise posing a serious threat to the environment through global warming.

Keywords: Conventional Concrete, Phosphogypsum, Thermosetting Plastics, Compressive Strength, Flexural Strength, Tensile Strength, Workability

I. INTRODUCTION

Vibration might be brought about by natural powers following up on a structure, for example, wind or earthquakes, or by an apparently harmless vibration source causing reverberation that might be ruinous, terrible or basically badly arranged. The seismic waves will make structures influence and waver in different manners relying upon the recurrence and heading of ground movement, and the tallness and development of the structure. Seismic movement can cause extreme motions of the structure which may prompt even auxiliary disappointment. The power of wind against tall structures can make the head of high rises move significantly in excess of a meter. This movement can be through influencing or winding. Certain points of wind and streamlined properties of a structure can emphasize the development and cause movement infection in inhabitants and posture genuine functionality issues. To upgrade the useful execution of the structure against seismic and wind powers, an appropriate structure configuration is performed utilizing elective basic frameworks and by usage of different vibration control equipment.

With the rapid economic development and advanced technology, civil 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. Therefore, these flexible structures are susceptible to be exposed to excessive levels of vibration under the actions of a strong wind or earthquake. To protect such civil structures from significant damage, the response reduction of civil structures during dynamic loads such as severe earthquakes and strong winds has become an important topic in structural engineering. An earthquake is a natural phenomenon associated with violent shaking of the ground. They are vibrations of the earth’s surface caused by sudden movements of earth crust mostly due to tectonic movements. Since earthquake forces are random in nature and unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. Earthquake loads are to be carefully modelled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. A different storey building such as 10th, 12th, 14th, 16th, 18th, and 21th storey building is selected which is subjected to dynamic loading earthquake. Under the increasing urban population density, scarcity of land and housing shortfalls, there is necessity of high-rise buildings.

The number of Tall buildings constructed nowadays has increased. Most of these buildings have a low natural damping. So, there is a need to increase the damping capacity of a structural system in the new generation of tall and super-tall buildings. The control of vibrations induced in the buildings by seismic waves is achieved by modifying rigidities, masses, damping and shape or by providing passive or active counter forces. Some of the methods provide a possibility of improving efficiency. The selection of a vibration control device is based on a number of factors such as efficiency, compactness, weight, capital cost, operating cost, maintenance requirements and safety.

Passive energy dissipation systems utilize a number of materials or devices for increasing damping, stiffness and strength. Passive energy dissipation systems are characterized by the efficiency to dissipate energy in a structure. Energy dissipation is achieved by the conversion of kinetic energy into heat or by transferring energy between vibrating modes. The latter method consists of secondary oscillators, which act as dynamic vibration absorbers.

The energy absorbed by the displacement-activated damper is through the relative displacement of the points of connections within the structure. Therefore, the behaviour is independent of the frequency of motion and the damper is in-phase with internal forces generated at the end of each vibration cycle corresponding to the peak deformations of the structure. The energy absorbed by the velocity-activated damper is through the relative velocity between the points of connection. Therefore, the behaviour depends upon the frequency of motion and the damper is out-of-phase with internal forces generated at the end of each vibration cycle corresponding to the peak deformations of the structure.

Motion – Activated Dampers are secondary masses that absorb structure's vibration energy through structures' motion. They are tuned to resonate with the main structure, but remain out-of-phase with the structure. These dampers absorb the input energy of a structure and dissipate by introducing extra forces to the structure so that a less amount of energy is stored in the main structure. Table I shows the types of passive energy dampers (Chang, C. H., and Soong, T T 1980).

A. Tuned Mass Damper

The concept of Tuned Mass Damper came into existence in the 1940s. The spring and damping elements are secondary masses of the structure which provides a frequency dependent physical phenomenon to increase damping in the primary structure. Nowadays, numerical and experimental studies have been carried out on the effectiveness of Tuned Mass Dampers in reducing the seismic response of structures. Tuned Mass Damper system is a well-accepted strategy in the area of vibration control of flexible structures particularly for tall buildings. The mechanism of suppressing structural vibrations by attaching a Tuned Mass Damper to the structure is to transfer the vibration energy of the building to the Tuned Mass Damper and to dissipate the energy. In other words, the frequency of the damper is tuned to a particular structural frequency, so that when that frequency is excited, the Tuned Mass Damper will resonate out of phase with the structural motion (Den Hartog, J. P., 1947). Properly designed tuned mass damper has the following functions:

1) Reduced displacements, accelerations, internal stresses and strains.
2) Increase structural safety. (i.e., the collapse of a building becomes less probable and hence, human life is protected).
3) Improve serviceability of the structure. (i.e., damage and corresponding repair cost in case of seismic events are reduced significantly)

1) Classification of Tuned Mass Dampers

Tuned Mass Dampers are divided into two groups, i.e., vertically and horizontally working devices. The application depends on the shape of the disturbing mode as well as on the position/direction of the TMD in order to reduce the vibration.

a) Vertically Acting Tuned Mass Dampers

Vertically Acting Tuned Mass Dampers are supported on helical steel springs. The frequency depends on mass and spring stiffness. The spring system is designed as a hanger system so that the springs are loaded in tension and also combined application with tension and compression springs is possible.

b) Horizontally Acting Tuned Mass Dampers

It consists of a horizontally swinging mass, which is placed between steel springs. A damping element is arranged in parallel to the springs. The horizontal stiffness of the springs as well as the shape of the mass is responsible for the target frequencies. The flexibility is achieved by the horizontal motion of the mass at the bottom of the hanger system. The mass works in one direction only, but it may also work on the horizontal plane.

B. Optimization of Tuned Mass Damper parameters

The basic principles of Tuned Mass Dampers of reducing structural response are well-established, but optimal Tuned Mass Damper configuration is quite a different problem (Richard Lourenco 2011). In the design of any control device for the suppression of undesirable vibrations, the aim would be to provide optimal damper parameters to maximize its effectiveness. A typical tuned mass damper consists of a mass 'm' which moves relative to the building and is attached to it by a spring with a stiffness 'k' and a viscous damper with coefficient 'c'.

A Tuned Mass Damper is characterized by its tuning, mass and damping ratios. The tuning ratio 'f' *is* defined as the ratio of fundamental frequency of the Tuned Mass Damper 'ωt' to that of the building 'ωo'. Thus,

$$f = \omega t / \omega o$$

Mass ratio μ is

$$\mu = m / M$$

Where,

M is the total mass of a Single Degree of Freedom structure or the generalized mass of a Multi Degree of Freedom structure, computed for a unit modal participation factor.

Damping ratio is given by

$$\xi = c / 2m\omega t$$

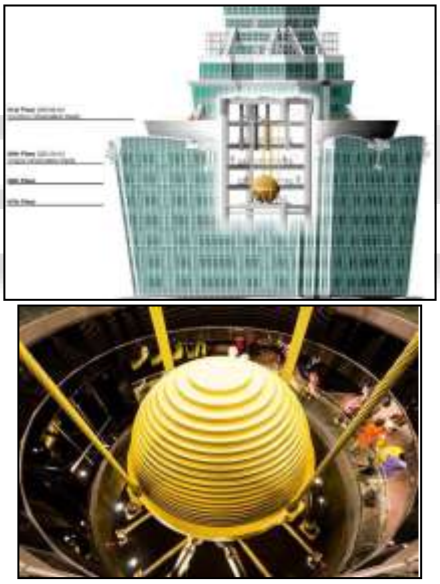


Fig. 1: Tuned Mass Damper in Taipei 101.

II. OBJECTIVES OF THE STUDY

- To understand the behavior of TMD (tuned mass damper) structural system available in literature for asymmetrical buildings.
- To understand the dynamic linear Analysis or response spectrum analysis (RSA).
- To find out the maximum and minimum displacement and storey drift under Response spectrum analysis by placing the TMD (tuned mass damper) at different locations in asymmetrical building.
- To understand the formation of spectral acceleration under the action of response spectrum analysis.

- To find out the spectral acceleration and base shear under the response spectrum analysis by providing the TMD (tuned mass damper) at different locations.

III. METHODOLOGY

In this section, the concept of the tuned mass damper is illustrated using the two-mass system shown in Figure below. Here, the subscript *d* refers to the *tuned mass damper*; the structure is idealized as a single degree of freedom system. Hence the following notation can be defined as,

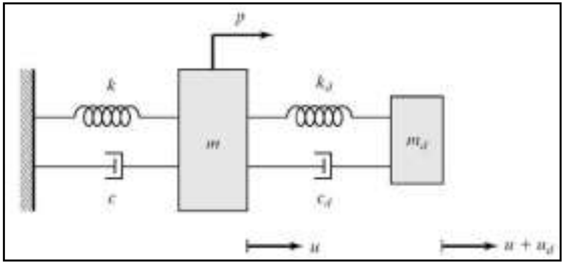


Fig. 2: SDOF-TMD System

and the equation of motion for the tuned mass is given by:

$$u\ddot{u}dd + 2\xi\xi dd\omega\omega dd u\dot{u}dd + \omega\omega dd2uudd = -u\ddot{u}$$

The purpose of adding the mass damper is to limit the motion of the structure when it is subjected to a particular excitation. The design of the mass damper involves specifying the mass $mmdd$, stiffness $kkdd$, and damping coefficient $ccdd$. The damper is tuned to the fundamental frequency of the structure such that

$$\omega\omega_{dd} = \omega\omega$$

The stiffness's for this frequency combination are related by

$$kk_{dd} = mmkk$$

Considering the primary mass is subjected to the following periodic sinusoidal excitation,

$$pp = p\hat{p} \sin \Omega\Omega\Omega\Omega$$

then the response is given by

$$uu = uu \sin(\Omega t + \delta 1)$$

$$uudd = uudd \sin(\Omega t + \delta 1 + \delta 2)$$

where uu and δ denote the displacement amplitude and phase shift, respectively. The critical loading scenario is the resonant condition, Ω = ω.

A. *Design of a Tuned Mass Damper*

The design of a damped TMD for an un-damped structure involves the following steps:

- Establish the allowable values of displacement of the primary mass and the TMD for the design loading.
- Determine the mass ratios required to satisfy these motion constraints. Select the largest value of mm.
- Determine $ffooppoo$:
- Compute $\omega\omega dd$:
- Compute $kkdd$.
- Compute $ccdd$
- Determine Pendulum Length (L):

The equation of motion of the frame structure subjected to external dynamic force p (t):

The dynamic response of the structure to this excitation is defined by the displacement u (t), velocity (t) and acceleration (t) (Ramancharla Pradeep Kumar, NPTEL). The external force is distributed among the three components of the structure.

Thus,

$$fS + fD + f I = p (t)$$

f_S is the stiffness component and is associated with displacement u such that

$$f_S = ku$$

Where,

k is the stiffness matrix of the structure and is a symmetric matrix (i.e., kij = kji).

f_D is the damping component and is associated with velocity such that

$$f_D = c$$

Where c is the damping matrix of the structure

f_I is the mass component is associated with acceleration such that

$$f_I = m$$

Substituting above equations gives Equation of motion:

$$m + c + ku = p (t)$$

Where,

m is the global mass matrix of the 2D frame structure

c is the global damping matrix of the frame structure (Assumed to be a zero matrix, as the damping is neglected in the structure)

k is the global stiffness matrix of the 2D frame structure

u is the global nodal displacement vector

p (t) is the external force

is acceleration vector

is velocity vector

u is displacement vector

Natural Frequency of the structure

$$wa = \sqrt{(k/m)} = \sqrt{(stiffness/mass)}$$

Time period Tn = 2π/wn

Total weight of the building	6235 KN
Weight of TMD – 5% of total weight	312 KN
Time period	3.226
Length of TMD	2.6 m.
Stiffness K	120 KN/m
DAMPING RATIO ζ	0.05
Effective Damping C	60.604 KN – s/m

B. *Model Considered for Analysis*

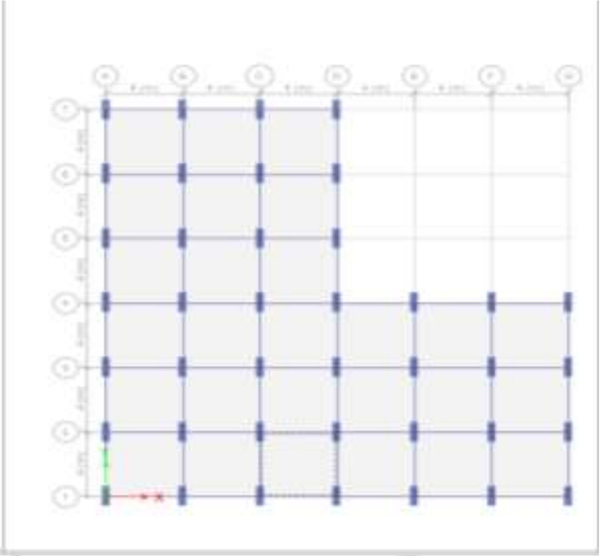
Different models for L- shaped G+20 storey Building with and without mass tuned have been prepared and compared in zone V as per IS 1893:2016.

The dimensions of beams, columns and slab are mentioned below and other data used for the purpose of analysis have been taken from IS 1893:2016

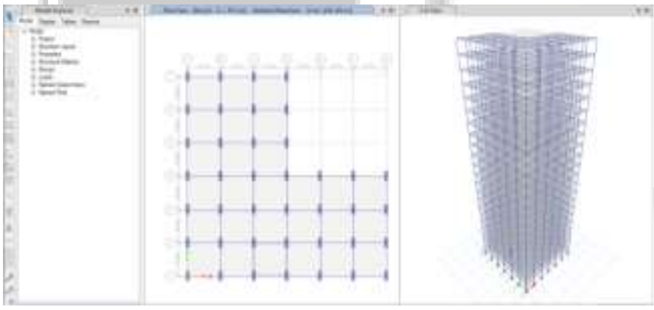
General Properties	
Location of Building	North India
No. of storeys	G+20
Typical Storey Height	3.6 m.
Size of Column	400 mm x 1200 mm
Size of Beam	400 mm x 600 mm
Thickness of Slab	150 mm.
Thickness of Wall	230 mm.
Material Properties	
Grade of Concrete	M 40
Grade of Steel Rebar	Fe 500
Type of Loading	
Wall Load	13.5 KN/m
Live Load	2 KN/m^2

Floor Finishing	1.5 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Type of Soil	II - Medium
Building Type (R)	5 (SMRF)

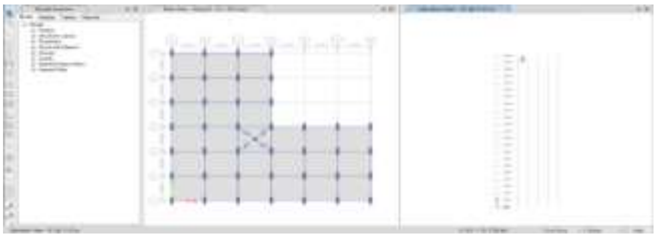
1) *Plan of the Building*



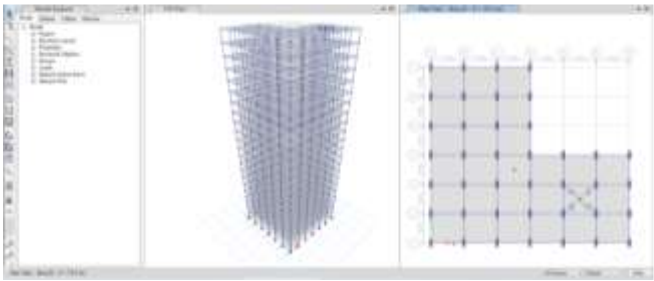
MODEL 1 – L SHAPE BUILDING WITHOUT TMD



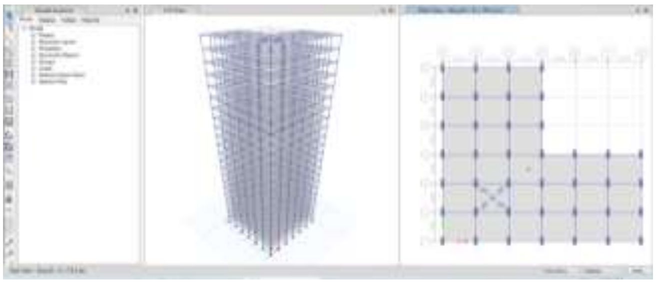
MODEL 2 – L SHAPED BUILDING WITH TMD AT ITS C.G.



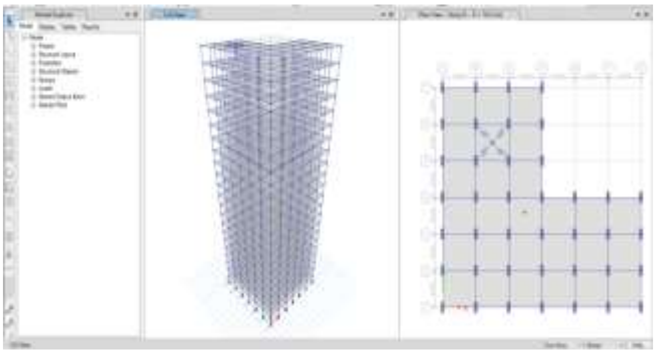
MODEL 3 – TMD AT CENTRE OF BOTTOM LEG OF L SHAPED BUILDING



MODEL 4 – TMD AT CENTRE OF CENTRAL PORTION OF L SHAPED BUILDING

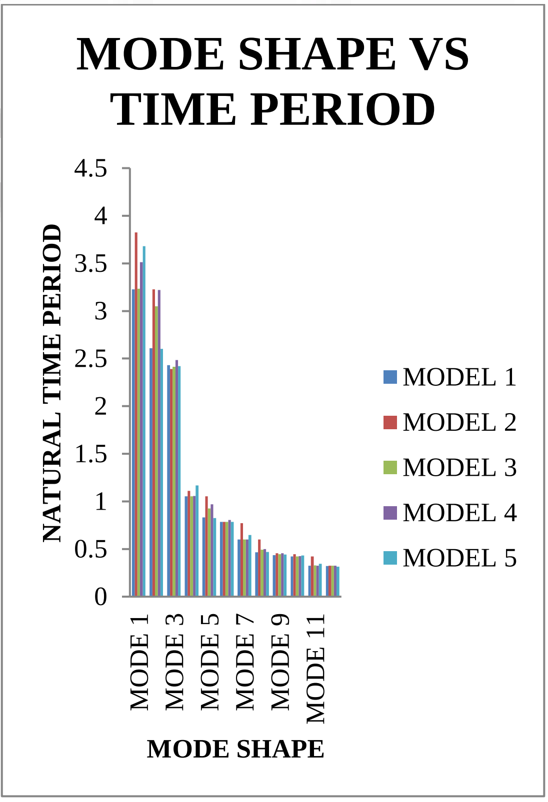


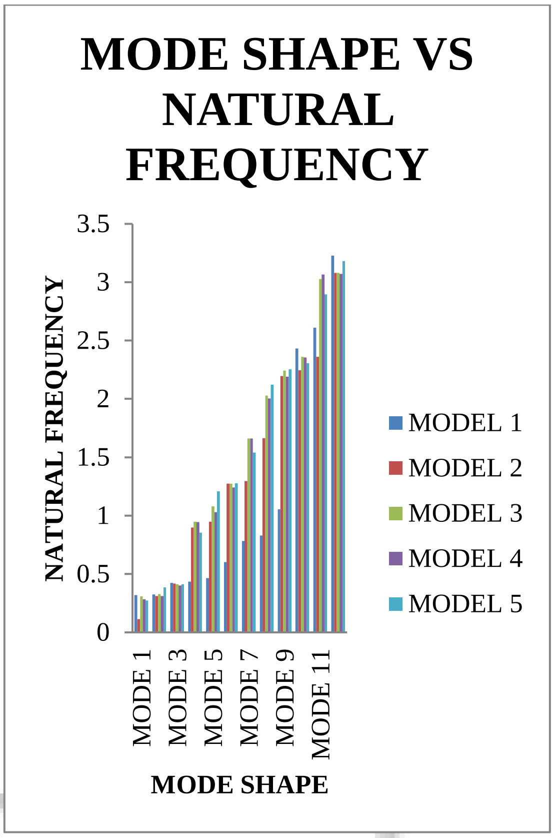
MODEL 5 – TMD AT CENTRE OF TOP LEG OF L SHAPED BUILDING

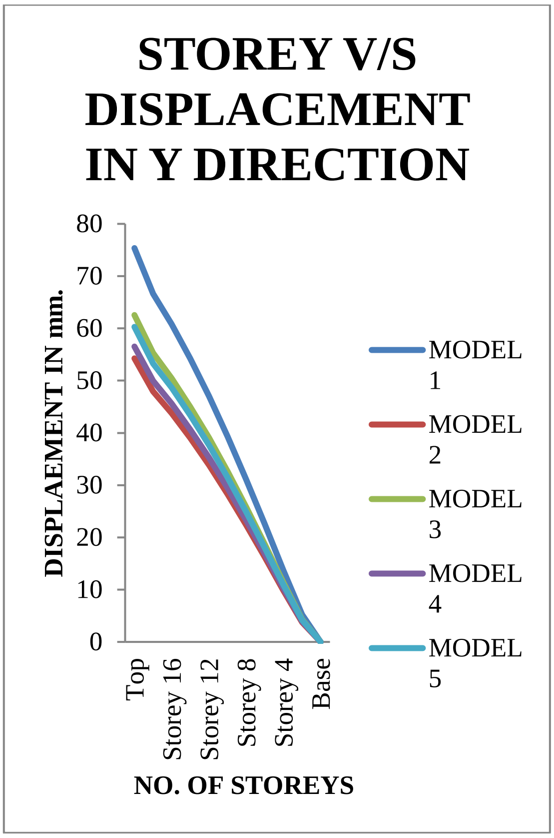


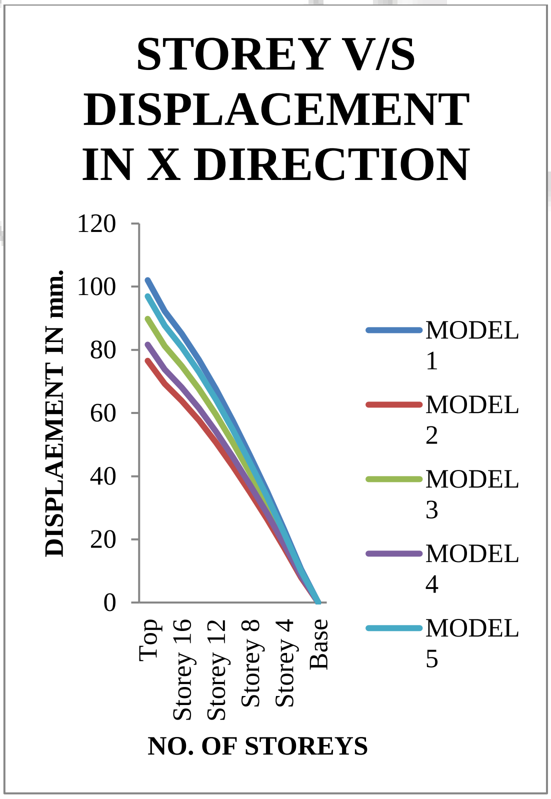
IV. RESULTS

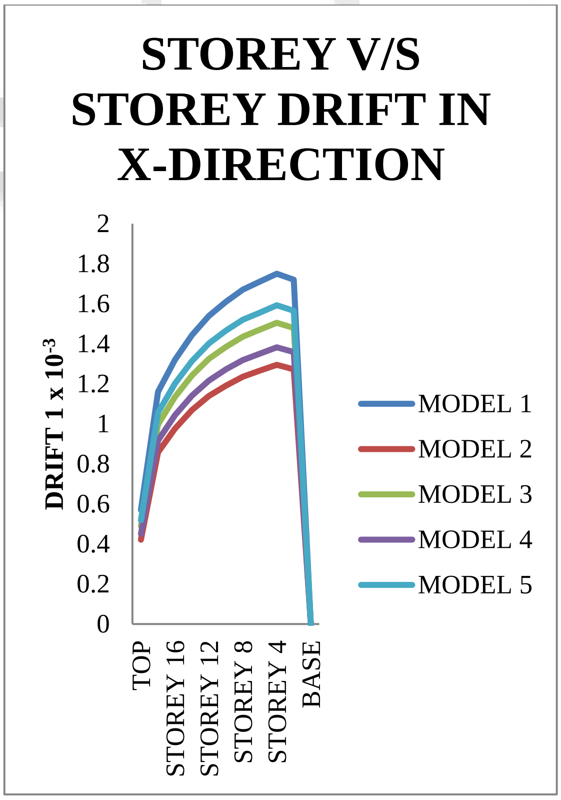
The results of these building models are presented here. The analysis carried out is Response Spectrum (Linear Dynamic) analysis.

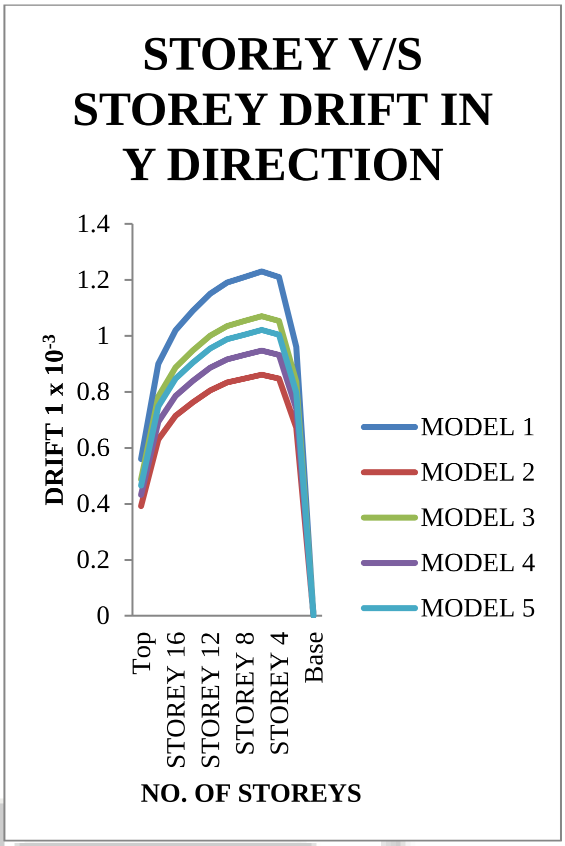


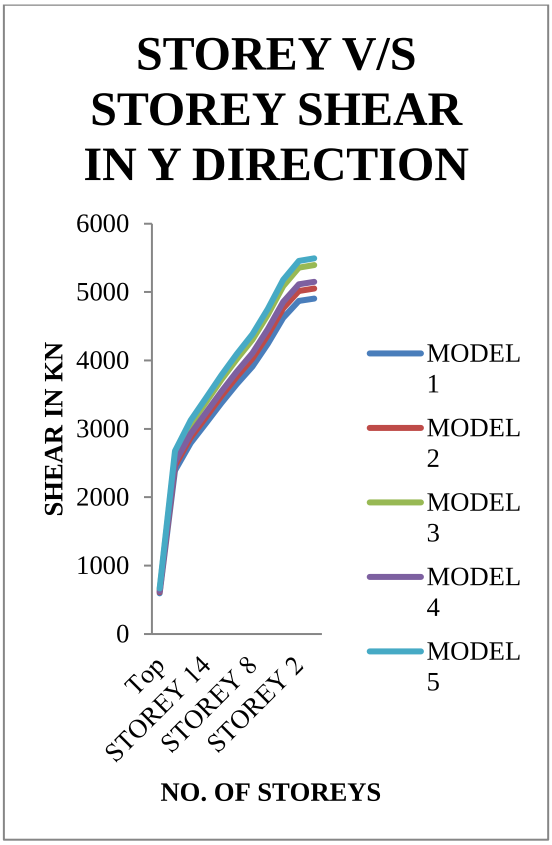

MODE SHAPE VS NATURAL FREQUENCY
NATURAL FREQUENCY
3.5
3
2.5
2
1.5
1
0.5
0
MODE 1
MODE 3
MODE 5
MODE 7
MODE 9
MODE 11
MODE SHAPE
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5

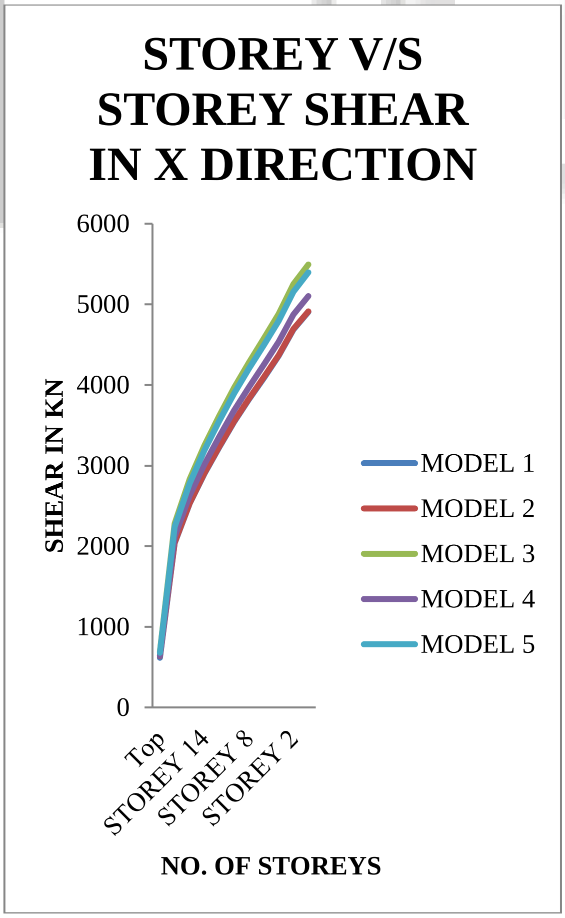

STOREY V/S DISPLACEMENT IN Y DIRECTION
DISPLAEMENT IN mm.
80
70
60
50
40
30
20
10
0
Top
Storey 16
Storey 12
Storey 8
Storey 4
Base
NO. OF STOREYS
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5

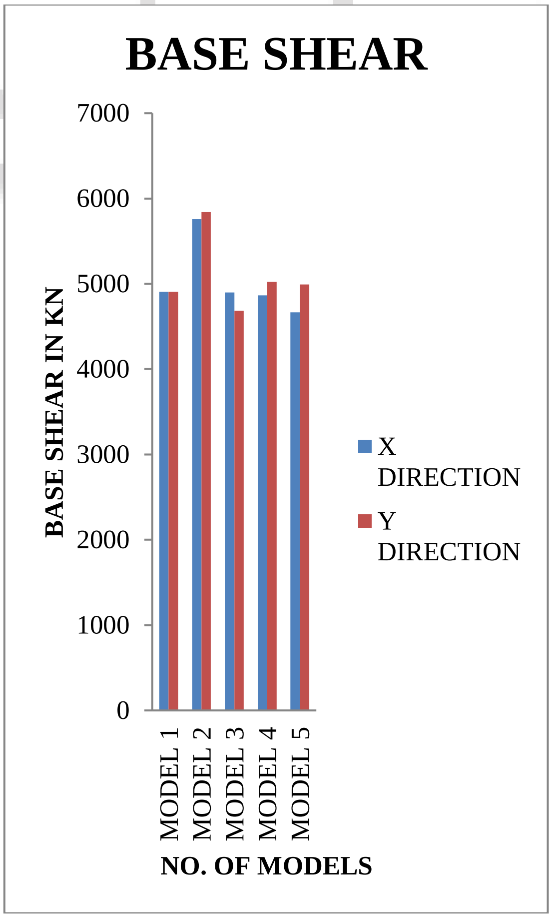

STOREY V/S DISPLACEMENT IN X DIRECTION
DISPLAEMENT IN mm.
120
100
80
60
40
20
0
Top
Storey 16
Storey 12
Storey 8
Storey 4
Base
NO. OF STOREYS
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5


STOREY V/S STOREY DRIFT IN X-DIRECTION
DRIFT 1 x 10-3
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
TOP
STOREY 16
STOREY 12
STOREY 8
STOREY 4
BASE
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5


STOREY V/S STOREY DRIFT IN Y DIRECTION
DRIFT 1 x 10-3
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Top
STOREY 16
STOREY 12
STOREY 8
STOREY 4
Base
NO. OF STOREYS
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5


STOREY V/S STOREY SHEAR IN Y DIRECTION
SHEAR IN KN
6000
5000
4000
3000
2000
1000
0
Top
STOREY 14
STOREY 8
STOREY 2
NO. OF STOREYS
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5


STOREY V/S STOREY SHEAR IN X DIRECTION
SHEAR IN KN
6000
5000
4000
3000
2000
1000
0
Top
STOREY 14
STOREY 8
STOREY 2
NO. OF STOREYS
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5


BASE SHEAR
BASE SHEAR IN KN
7000
6000
5000
4000
3000
2000
1000
0
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
NO. OF MODELS
X DIRECTION
Y DIRECTION

V. Conclusion

The seismic behaviour of G+20 storey building with tuned mass damper and without tuned mass damper was investigated. TMD is effective in reducing displacement and acceleration and, thereby, can be used for structures under earthquake. This study is aimed as tuned mass dampers in reducing structural (storey drift, storey displacement and base shear) of seismically excited building.

– It has been found that the TMDs can be successfully used to control vibration of the structure.
– Finally, based on findings in this study, when the first mode of a MRF building dominates the structural response, a response reduction of the MRF building, using TMD under earthquake loading, can be achieved.
– For the L Shape building, 5% TMD is found to effectively reduce top storey displacement. Therefore, the TMD should be placed at top floor for best control of the first mode.
– Maximum response reduction was observed for the Tuned Mass Damper located at centre of gravity for such asymmetrical building. So, the optimum location of Tuned Mass Damper is at its centre of gravity for this configuration of building.
– For a 20 storey building, when the Tuned Mass Damper of mass ratio 5% is used at the centre of gravity, the joint displacement and storey drift are reduced up to 23% and 20% respectively and base shear is increased up to 22%.
– The columns on which the Tuned Mass Damper rests should be designed for maximum forces, as the maximum shear forces are found in Tuned Mass Damper columns when the building is subjected to seismic forces.

From analysis it can be seen that it is necessary to properly implement and construct a damper in any high rise building situated in earthquake prone areas.

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