A Study on Behavior of RCC Building with Tuned Mass Dampers and Stiffness Irregularities

Tejas H K
M.Tech, Structural Engineering Department
SJB Institute of Technology Bangalore,
Karnataka, India

Srinivas K S
Assistant Professor
SJB Institute of Technology
Bangalore, Karnataka, India

Abstract— **This is an Analytical study which will illustrate the behavior of a RCC building vulnerable to seismic activity by analyzing Tuned Mass Dampers. In this study water tanks will be modeled as Passive tuned dampers on top storey of the building structure. The dynamic analysis such as Response Spectrum and El-Centro time history analysis will be carried out as per IS 1893:2016 Part-1. A square RCC building will be considered to have H/D=1.63. The TMD's will be modeled with total mass ratio of 2.5%, 5.0%, 7.5% and 10% of first mode with a mass source of (1DL+0.25LL) and with the Damping ratio of 5% along with the vertical irregularity by implementing soft storey at bottom, middle and top storey of the structure. The behavior of the structure in Zone II, III, IV and V will be analyzed and modeled in ETABS 2016. The response such as Time Period, Mass Participating ratio, Base Shear, Storey Drift, Storey Displacement and Acceleration for all 48 models will be recorded.**

Keywords—mass damper: seismic loading: RCC square building: stiffness irregularities: ETABSv16

I. INTRODUCTION (*Heading 1*)

Earthquake may be defined as a wave like motion generated by forces in constant turmoil under the surface layer of the earth (lithosphere), travelling through the earth's crust.

Seismic control systems refer to those modern techniques in Earthquake Resistant Design that prevent or divert a major portion of earthquake energy from entering into the main structural system of the structure by applying various techniques. Earthquakes remain largely unpredictable and potentially catastrophic, a matter of continuous concern to communities in affected zones. Tuned mass dampers (TMD) have been widely used for vibration control in mechanical engineering systems. In recent years, TMD theory has been adopted to reduce vibrations of tall buildings and other civil engineering structures. TMD 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 when that frequency is excited, the damper will resonate out of phase with the structural motion. The mass is usually attached to the building via a spring-dashpot system and energy is dissipated by the dashpot as relative motion develops between the mass and the structure.

Types of control system:

1. Passive Control System: A number of passive energy dissipation systems are currently in use for the protection of structures against seismic and wind excitations. . The term "passive" is used to indicate that these systems do not require an external power source for their operation. Typically, the mechanical properties of the passive control systems cannot be modified. These systems utilize the motion of the structure to produce relative motion within the damping devices, which in turn dissipate energy. Passive energy dissipation systems dissipate energy input through a variety of mechanisms including the yielding of mild steel, viscoelastic action in rubber-like materials, shearing of viscous fluid, orificing of fluid, sliding friction etc. The different types of passive energy dissipation devices are Base isolators, dampers, energy dissipaters, etc.

2. Active Control System: This method involves the process of imposing forces on the structure in order to counterbalance the earthquake forces acting on the building structure. This system requires additional energy source and computer -controlled actuators to operate. Hence, this system is complex compared with the passive seismic control systems. Active control system is a new invention compared with passive systems. When an earthquake hits a building, the sensors of active control system determine the direction and the weight of the counterbalance force to be induced in opposite direction so that the building remains motionless and structure remains safe. Hence, the whole arrangement and requirement of an active seismic control system is complex and expensive. This is not suitable for small projects. The different types of passive energy dissipation devices are active mass dampers, fluid dampers, etc.

Tuned Mass Damper (TMD): 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 when 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.

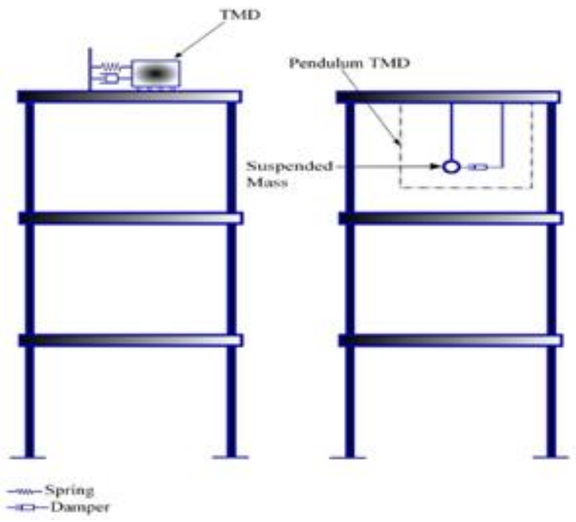

Fig 1: Tuned Mass Damper

Tuned mass dampers are placed in structures where the horizontal deflections from the seismic force are felt the greatest, effectively making the building stand relatively still. When the building begins to oscillate or sway, it sets the TMD into motion by means of the spring and, when the building is forced right, the TMD simultaneously forces it to the left. Ideally, the frequencies and amplitudes of the TMD and the structure should nearly match so that EVERY time the wind pushes the building, the TMD creates an equal and opposite push on the building, keeping its horizontal displacement at or near zero. If their frequencies were significantly different, the TMD would create pushes that were out of sync with the pushes from the wind, and the building's motion would still be uncomfortable for the occupants. If their amplitudes were significantly different, the TMD would, for example, create pushes that were in sync with the pushes from the wind but not quite the same size and the building would still experience too much motion. The effectiveness of a TMD is dependent on the mass ratio (of the TMD to the structure itself), the ratio of the frequency of the TMD to the frequency of the structure (which is ideally equal to one), and the damping ratio of the TMD (how well the damping device dissipates energy). Wide span structures (bridges, spectator stands, large stairs, stadium roofs) as well as slender tall structures (chimneys, high rises) tend to be easily excited to high vibration amplitudes in one of their basic mode shapes, for example by wind or marching and jumping people. Low natural frequencies are typical for this type of structures, due to their dimensions, as is their low damping.

II. METHODOLOGY

A 5 bay 16 story reinforced concrete space frame made up of M40 grade concrete and Fe 500 grade steel is considered in this study. A square plan is considered with width of each bay being 6m. Story height of 3.2m and soft storey of 4.0m is taken. Hence the total width and height of the frame are 30m and 52m respectively. The support conditions are assumed to be fixed and soil structure interaction effects are neglected. A modal damping of 5% of critical is considered in all modes in order to account for the material damping. The beam and column sizes are taken as 300 x 750mm and 600 x 600mm respectively and are modelled as frame elements. Slabs are modelled as thin shell element with a thickness of 200mm. Wall thickness is assumed as 300mm and is acting on the peripheral beam and a live load of 3kN/m2 on floors and 1.5kN/m2 on roof are considered. As per IS 1893:2002 (Part 1), a live load reduction factor of 0.5 for all floors except roof is applied in seismic analysis. The loads on the frame and other preliminary data of the framed structure are tabulated. The modelling and analysis was done in ETABS 2016

The modelling of Damper is slightly more challenging to model a pendulum which is free to translate in 3D. In this case, a linear link is created to represent the pendulum device. Select Define > Section Properties > Link/Support Properties, then define translational stiffnesses along U1, U2, and U3. The linear stiffness along U1 represents axial properties, and should be based on the EA/L value of the hangers. The linear stiffness properties of U2 and U3 are chosen as Mg/L.

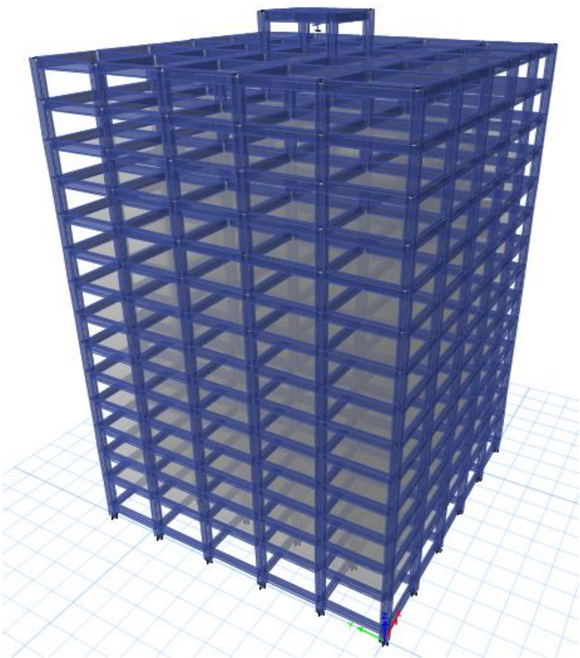

Fig 2: Model with TMD

III. RESULTS AND DISSCUSSION

The 5 bay 16 story space frame described in the previous chapter was analyzed under zone II, III, IV and V and the response for time history and response spectrum were recorded. The recorded values were tabulated and were plotted graphically for better understating of the results. The results are used to conclude the suitability of mass dampers for different seismic zones of India. The optimal values of damping coefficient and damping exponent of the mass dampers are determined first for each seismic zone and then the response of the damped structure such as storey displacement, storey drift, time period, modal mass

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participating ratio and acceleration are compared with that of the frame without supplemental dampers.

1. Time Period

It is the time taken by the building to undergo one complete cycle of oscillation.

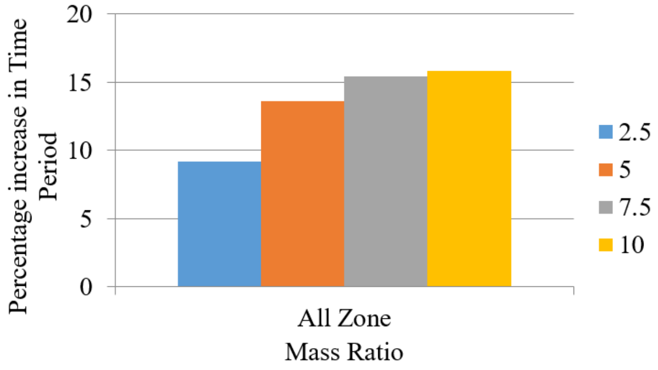

Fig 3: Percentage increase in Time period for soft storey at Bottom.

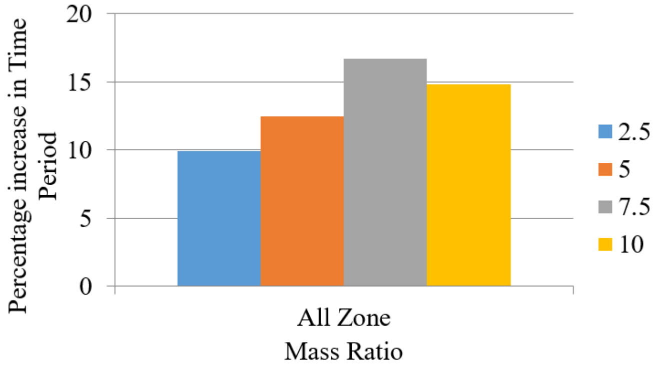

Fig 4: Percentage increase in Time period for soft storey at Middle.

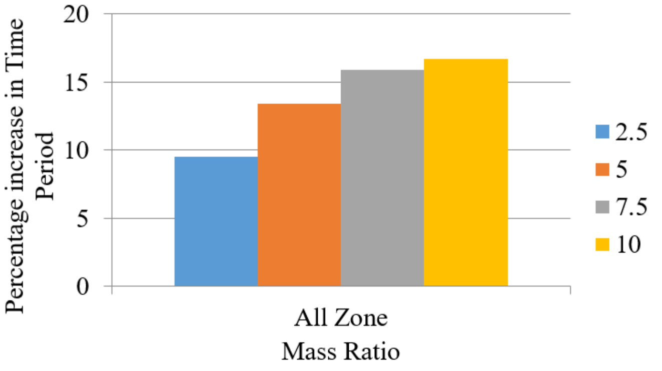

Fig 5: Percentage increase in Time period for soft storey at Top.

The above figures represents the graphical representation of Percentage increase in Time Period and Mass Ratio for the structure having a soft storey at the Bottom, Middle and Top. We can observe as the mass ratio increases there is an increase in the Time Period of the structure.

2. Modal Mass Participation Ratio

The value of modal participating ratio for each vibration mode represents the participation of each mode in the structural responses, when a structure equipped with TMD a vibration mode is added to the others.

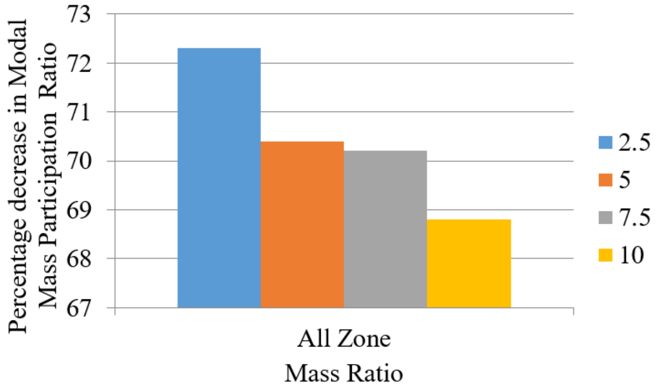

Fig 6: Percentage decrease in Modal Mass Participation Ratio for soft storey at Bottom.

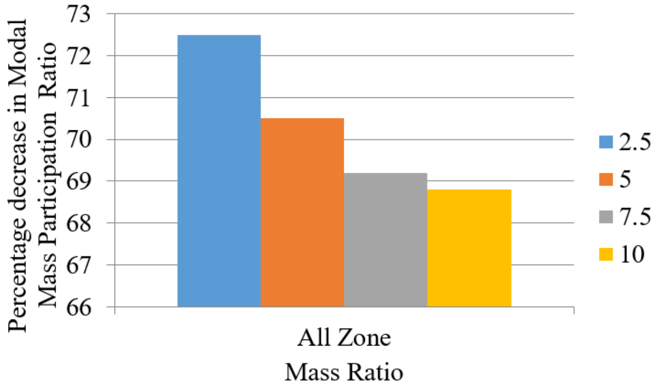

Fig 7: Percentage decrease in Modal Mass Participation Ratio for soft storey at Middle.

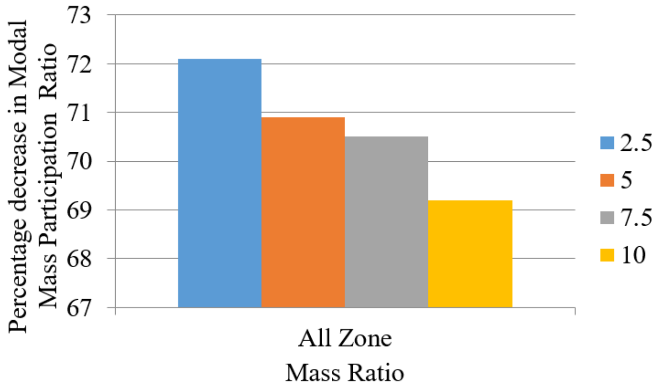

Fig 8: Percentage decrease in Modal Mass Participation Ratio for soft storey at Top.

The above figures represents the graphical representation of percentage decrease in Modal Mass Participating Ratio and Mass Ratio for the structure having a soft storey at the Bottom, Middle and Top. We can observe as the mass ratio increases there is decrease in the Modal Mass Participating Ratio of the structure.

3. Base Shear

It is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity.

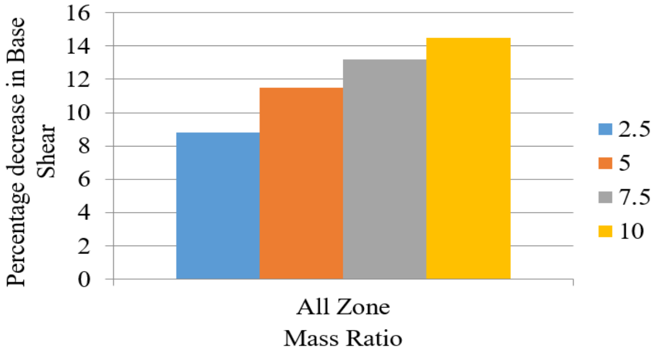

Fig 9: Percentage decrease in Base Shear for soft storey at Bottom.

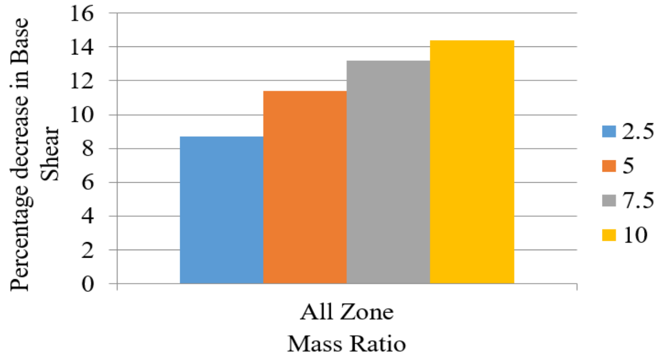

Fig 9: Percentage decrease in Base Shear for soft storey at Middle.

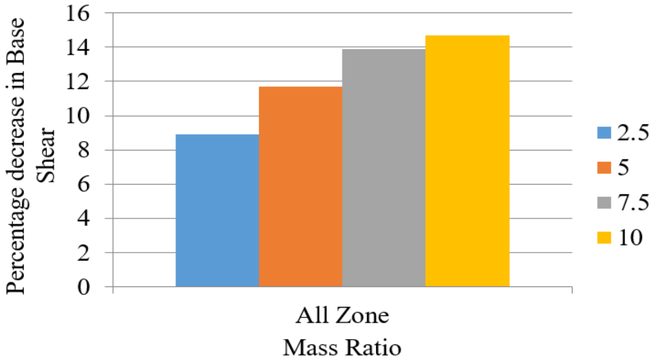

Fig 9: Percentage decrease in Base Shear for soft storey at Top.

The above figures represents the graphical representation of percentage increase in Base Shear and Mass Ratio for the structure having a soft storey at the Bottom, Middle and Top

4. Acceleration

It is the rate at which the velocity of the storey changes with respect to time.

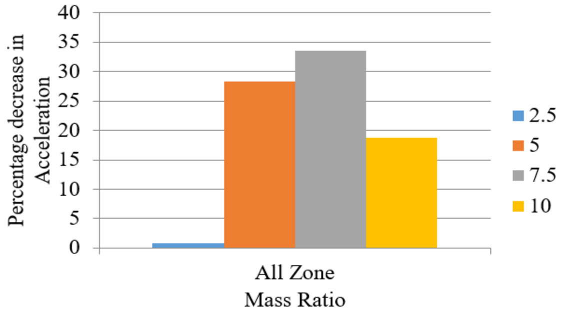

Fig 10: Percentage decrease in Acceleration for soft storey at Bottom.

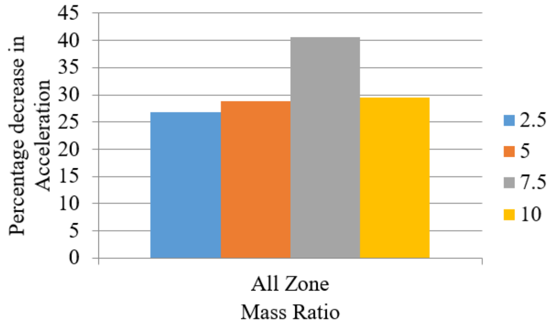

Fig 10: Percentage decrease in Acceleration for soft storey at Middle.

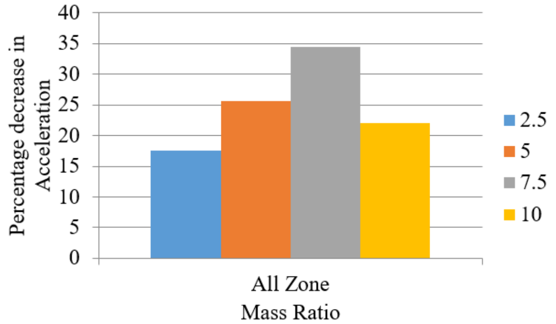

Fig 11: Percentage decrease in Acceleration for soft storey at Top.

The above figures represents the graphical representation of percentage variation in storey acceleration and Mass Ratio for the structure having a soft storey at the Bottom, Middle and Top.

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5. Storey Displacement

It is the lateral displacement of the story relative to the base. The lateral force resisting system can limit the excessive lateral displacement of the building.

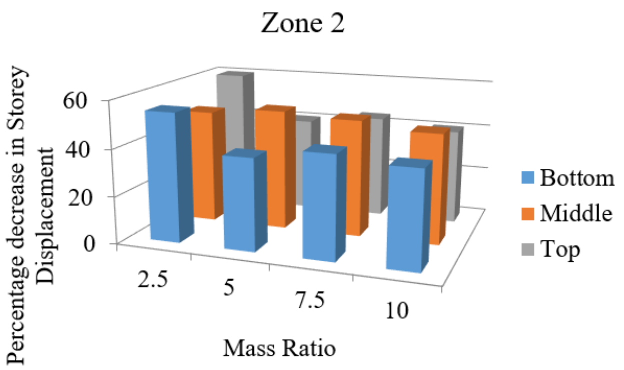

Fig 12: Percentage decrease in Storey Displacement for Zone2

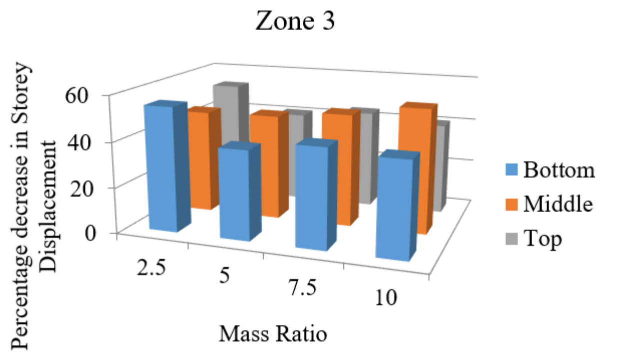

Fig 13: Percentage decrease in Storey Displacement for Zone3

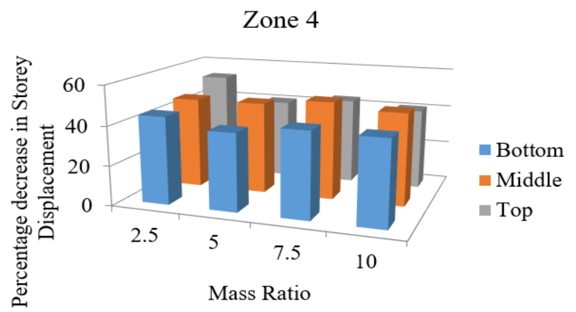

Fig 14: Percentage decrease in Storey Displacement for Zone4

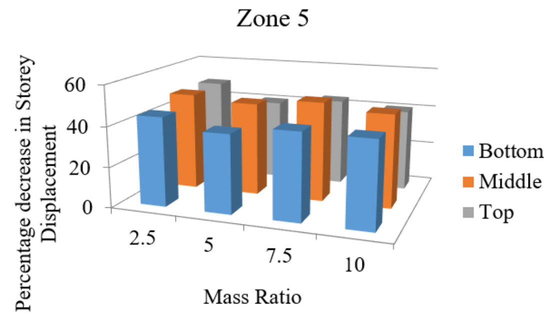

Fig 15: Percentage decrease in Storey Displacement for Zone5

The above figures represents the graphical representation of percentage variation in storey Displacement, Mass Ratio and Soft Storey location for the structure having a soft storey at the Bottom, Middle and Top.

6. Storey Drift

It is the relative displacement of one story relative to another.

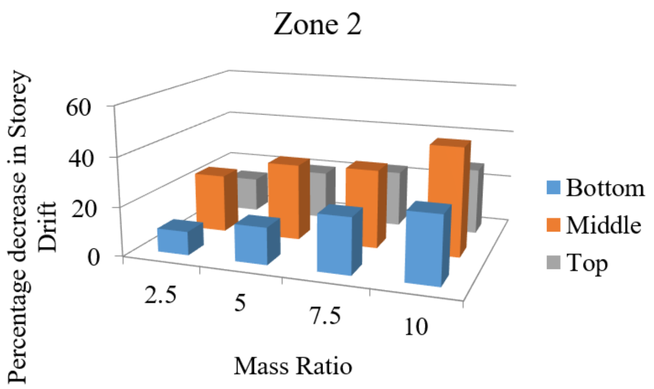

Fig 16: Percentage decrease in Storey Drift for Zone2

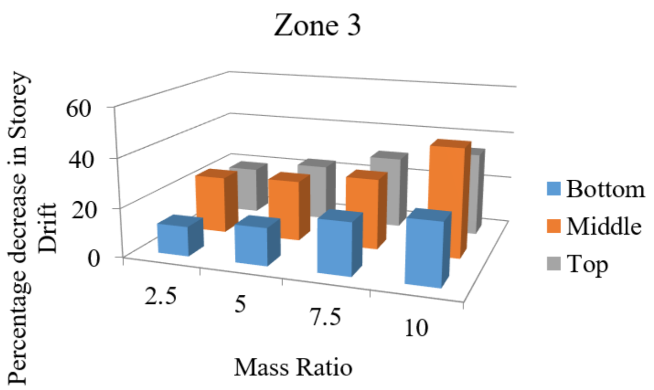

Fig 17: Percentage decrease in Storey Drift for Zone3

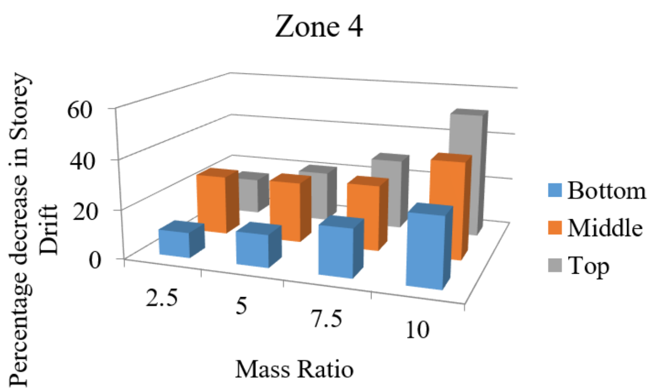

Fig 18: Percentage decrease in Storey Drift for Zone4

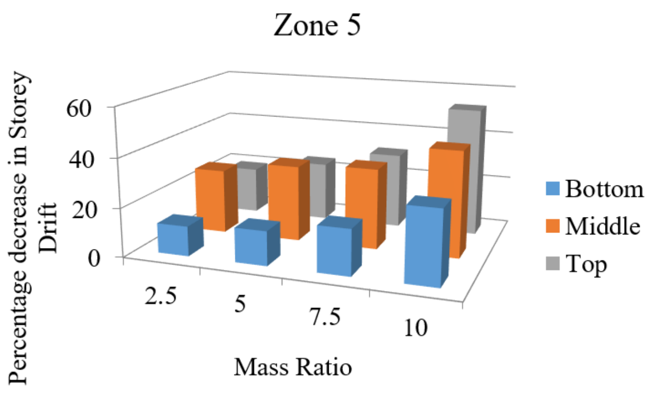

Fig 19: Percentage decrease in Storey Drift for Zone5

The above figures represents the graphical representation of percentage variation in storey Drift, Mass Ratio and Soft Storey location for the structure having a soft storey at the Bottom, Middle and Top.

IV. Conclusion

Non-linear time history analysis and Response Spectrum analysis was carried out on structures with and without tuned mass dampers. From the analyzed results it is observed that Damping Ratio is the primary variable in the Analysis of Tuned Mass Dampers. The Response of the structure varies with tuned mass ratio. As the mass ratio increases the time period also increases in the structures with soft storey at Bottom and Top. As the mass ratio increases the Modal mass participation ratio decreases in the structures with soft storey at Bottom, Middle and Top. As the mass ratio increases the Base Shear decreases in the structures with soft storey at Bottom, Middle and Top. As the mass ratio varies the Storey Acceleration decreases by 40.4% in the structure with soft storey at Middle for mass ratio 7.5% in all zones. For lower mass ratio the storey displacement is small. For structures with soft storey at top shows maximum decrease in storey displacement was observed. For higher mass ratio the storey drift is small. For structures lying in Zone2 and Zone3 with soft storey at middle shows maximum decrease in storey drift. For structures lying in Zone4 and Zone5 with soft storey at top shows maximum decrease in storey drift. As the mass ratio increases, response like Time period, Base Shear and Storey Drift will be reduced irrespective of zone for the structures having Soft Storey at bottom, middle and top.

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