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# Numerical Analysis and Validation of Irregularity in Moment Frame Structure Due to Varying Location of Tuned Mass Damper

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***Abstract:** Within the construction industry, the number of higher and lighter structures that are adaptable and have a low damping value has been steadily increasing in recent years. Those constructions will simply fail as a result of earthquake and wind-induced structural vibrations. There are a variety of approaches available today to reduce structural vibration, and one of the oldest is the use of dampers. The tuned mass damper is tuned to the structural frequency of the structure if the stiffness and damping values are kept constant. The main goal is to investigate the mass and torsional irregularity in the structure. This study is divided into two phases - first phase involves the investigation and validation of structure having tuned damper with varying location along the height of building. The second phase involves the location of tuned mass damper with the plan projection of the building. Non-Linear Time history analysis is used to identify the behavior of frame elements in the structure based on considered cases using ETABS. The parameters such as displacement was evaluated. The result shows that the dampers should be carefully placed in order to tune the frequency of the structure.*
***Keywords:** Tuned mass damper, Location, Eccentricity*

## I. INTRODUCTION

Alexander and Schilder (2009) proposed the performance of nonlinear tuned mass damper. A two degree of freedom system with a cubic nonlinearity is modeled. The nonlinearity is originated from geometric arrangement of two pairs of springs. One pair helps in providing linear stiffness whereas the other pair rotates as they extend and helps in hardening spring stiffness. Wong et. al. (2008) studied dissipation of seismic energy in inelastic structures with tuned mass dampers. By using the force analogy method, an inelastic structure is modeled which is chosen as the base of plastic energy dissipation analysis in the structure. Energy response reduction after using TMD is also studied by using plastic energy spectra for various levels of structural yielding. Ghosh and Basu (2004) observed the effect of soil structure interaction and concluded that when the soil becomes stiff, it allows the foundation to move relative to the surrounding soil which changes the soil foundation system from that of the fixed base. In such a case a conventional TMD loses its effectiveness in controlling the response of the structure to base excitation. Kwok and Samali (2006) carried out some experimental verifications of both active and passive TMD and compare the results with parametric study which are very useful in selection of optimal TMD parameters.

Lin et. al. (2010) studied the vibration control of seismic structures using semi-active friction multiple tuned mass dampers. In this paper a semi active friction type multiple tuned mass damper (SAF-MTMD) is developed to control vibration in seismic structures A comparison study is made with a passive friction type multiple tuned mass dampers and concluded that SAF-MTMD effectively reduces the seismic motion particularly at a larger intensity. Lourenco et. al. (2009) performed some experimental work taking a pendulum tuned mass damper with advantageous over conventional TMD. They did some simulation study considering the three dimensional behavior of pendulum mass and found that the frequency can be re tuned by changing the cable length. Wirsching and Campbell (1974) solved the problem of optimizing the TMD parameters and the natural frequency and damping ratio attached to the multi-story structure and analyzed the response of the first main mode of the main structure equipped with a TMD under the Earth lateral vibration of Gaussian white noise. Chouw et. al.(2004) studied the behavior of soil structure interaction with tuned mass dampers during near source earthquake at two different places varying the natural frequency of the dampers . They used the ground motions at the stations SCG and NRG of the 1994 Northridge earthquake for their study and concluded that soil structure interaction and ground motion can increase or decrease the effect of TMD. Li et. al. (2003) numerically observed the performance of multiple active-passive tuned mass dampers (MAPTMD) to prevent vibration of single degree of freedom structures subjected to ground acceleration with a uniform distribution of natural frequency.

The MAPTMD generates a controlling force by keeping the displacement and velocity response gain and changing the acceleration response gain. Farghaly and Ahmed (2012) discussed the design and application of TMD Study indicates the response of structure such as story displacements and shear force of columns can be reduced by using TMD especially with a specific arrangement in the model. Luciara Silva Vellar et. al.(2019) in this work, a new methodology for simultaneous optimization of parameters and positions of multiple tuned mass dampers (MTMDs) in buildings subjected to earthquakes is proposed. For illustration purposes, the proposed methodology is applied in a 10-storey building, confirming its effectiveness. Mohsen Khazaei et al. (2020) In this research, the performance of multiple tuned mass dampers (MTMDs) is investigated in L and U-shaped regular and irregular tall steel buildings with 10 and 20 floors, under the near- and far-field records. Nonlinear time history analysis is also applied to evaluate the multiple tuned mass dampers effects on the seismic responses of the structures. B. Islam and R. Ahsan (2012) they used El Centro NS earthquake to develop a computer program and found a higher percentage of reduction on the roof of a ten-story structure using TMD with the application of EVOP. The study shows the effectiveness of present approach in optimization leading to a more feasible selection of TMD parameters.

## II. OBJECTIVES OF THE STUDY

This research work has been undertaken with the following objectives:

*1)* To create a simpler model of a multistory building with identical parameters and to provide it with and without a tuned mass damper at the same time.
*2)* To conduct dynamic seismic analysis on the modelled structures using scaled recordings of acceleration time histories and compare the results.

## III. CONCEPTS OF TUNED MASS DAMPER

A tuned mass damper (TMD) is a passive control device that is attached to a structure and consists of a mass, a spring, and a damper to lower the structure's dynamic response. The damper inertia force, which acts on the structure, dissipates energy. It's been frequently employed in mechanical engineering systems for vibration control. Because of the easy and simple process, numerous theories have recently been applied to reduce vibration in civil engineering constructions. To provide optimum responsiveness, the secondary mass damper's natural frequency is constantly matched to that of the primary structure, so that when that frequency of the structure is excited, the TMD will resonate out of phase with the structural motion. The surplus energy stored in the structure is converted to secondary mass and dissipated as a result of relative motion created between them later. In this study Pendulum tuned mass damper is taken in to account.

### *A. Pendulum Tuned Mass Damper*

The problems associated with the bearings can be eliminated by supporting the mass with cables which allow the system to behave as a pendulum. Figure 1.4 (a) shows a simple pendulum attached to a floor. Movement of the floor excites the pendulum. The relative motion of the pendulum produces a horizontal force that opposes the floor motion. This action can be represented by an equivalent SDOF system that is attached to the floor, as indicated in Figure 1.4 (b).

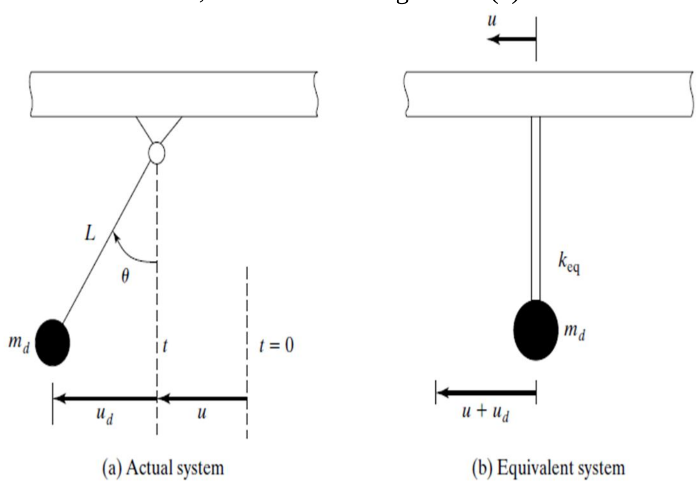


Fig. 1 A simple pendulum tuned mass damper

### *B. TUNED MASS DAMPER THEORY FOR MDOF SYSTEMS*

To deal with a MDOF system having a number of tuned mass dampers located throughout the structure we use the example of two DOF.

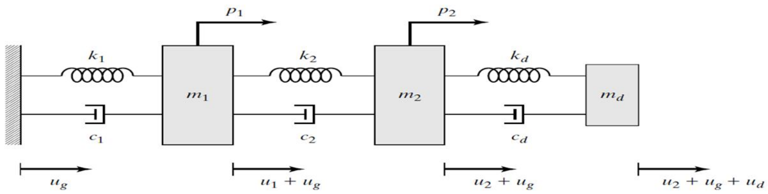


Fig. 2 Two-DOF system with TMD

For 2 DOF system having a damper attached to mass 2 is considered first to introduce the key ideas. The governing equations for the system shown in figure 3.4 are as follows-

$$m_1\ddot{u}_1 + c_1\dot{u}_1 + k_1 u_1 - k_2 (u_2 - u_1) - c_2 (\dot{u}_2 - \dot{u}_1) = p_1 - m_1 \ddot{u}_g \quad \text{.................................. (1)}$$

$$m_2\ddot{u}_2 + c_2 (\dot{u}_2 - \dot{u}_1) + k_2(u_2 - u_1) - k_d u_d - c_d \dot{u}_d = p_2 - m_2\ddot{u}_g \quad \text{.................................. (2)}$$

$$m_d\ddot{u}_d + k_d u_d + c_d\dot{u}_d = -m_d (\ddot{u}_2 + \ddot{u}_g) \quad \text{.................................. (3)}$$

Introducing matrix notation, equations (1) and (2) are written as,

$$M\ddot{U} + C\dot{U} + KU = \begin{bmatrix} p_1 - m_1\ddot{u}g \\ p_2 - m_2\ddot{u}g \end{bmatrix} + \begin{bmatrix} 0 \\ k_d u_d + c_d\dot{u}_d \end{bmatrix} \quad \text{.................................. (4)}$$

Where the various matrices are

$$U = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}, \quad M = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}, \quad K = \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \text{ and } C = \begin{bmatrix} C_1 + C_2 & -C_2 \\ -C_2 & C_2 \end{bmatrix}$$

Defining modal mass, stiffness, and damping terms,

$$\tilde{m}_i = \phi_i^T M \phi_i \quad \text{.................................. (5)}$$

$$\tilde{K}_i = \phi_i^T K \phi_i \quad \text{.................................... (6)}$$

$$\tilde{C}_i = \phi_i^T C \phi_i \quad \text{.................................. (7)}$$

Expressing the elements of $\phi_i$ as

$$\phi_i = \begin{bmatrix} \phi_{i1} \\ \phi_{i2} \end{bmatrix} \quad \text{.................................. (8)}$$

And assuming damping is proportional to stiffness

$$C = \alpha K \quad \text{.................................. (9)}$$

With this assumption, the modal damping ratio is given by

$$\xi_i = \frac{\tilde{c}_j}{2\omega_i \tilde{m}_i} = \frac{\alpha\, \omega_i}{2} \quad \text{.................................. (10)}$$

i =1, 2 (for mode 1 and 2 respectively)

Since a TMD is effective for a narrow frequency range, we have to decide on which modal resonant response is to be controlled with the TMD. Once this decision is made, the analysis can proceed using the selected modal equation and the initial equation for the TMD.

The mass ratio is defined in terms of the equivalent SDOF mass.

$$\bar{m} = \frac{m_d}{\tilde{m}_{1e}} \quad \text{.................................. (11)}$$

Given $\bar{m}$ and $\xi_e$ we find the tuning frequency and damper damping ratio. Tsai and Lin (1993) suggest equations for the optimal tuning parameters f and $\xi_d$ determined by curve fitting schemes. The equations are listed next for completeness:

$$f_{opt} = \left( \frac{\sqrt{1-.5\bar{m}}}{1+\bar{m}} + \sqrt{1-2\xi^2} - 1 \right) - (2.375 - 1.034\sqrt{\bar{m}} - 0.426\,\bar{m})\, \xi\sqrt{\bar{m}} - (3.730 - 16.903\sqrt{\bar{m}} + 20.496\bar{m})\, \xi^2\sqrt{\bar{m}} \quad \text{..................................(12)}$$

And,

$$\xi_{dopt} = \sqrt{\frac{3\bar{m}}{8(1+\bar{m})(1-.5\bar{m})}} + (0.151\,\xi - 0.170\,\xi^2) + (0.163\,\xi + 4.980\,\xi^2)\,\bar{m} \quad \text{.................................. (13)}$$

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The damper parameters are determined with

$$m_d = \bar{m}\,\tilde{m}_{1e} \quad \text{.................................. (14)}$$

$$\omega_d = f_{opt}\,\omega_1 \quad \text{.................................. (15)}$$

$$k_d = \omega_d^2\, m_d \quad \text{.................................. (16)}$$

$$c_d = 2\,\xi_{dopt}\,\omega_d\, m_d \quad \text{.................................. (17)}$$

## IV. EXPLANATION OF THE STUDY WORK

In this research work following are the case study involved. The study comprises in two stages in which 1st stage involves change in location of TMD along the height of building and 2nd stage involves change in location of TMD in the plan projection of building.

Table 1 General consideration having following cases

| CASES | Notation | Description |
|---|---|---|
| Based on Conventional building | WTMD | Residential building with no tuned mass damper |
| Based on change in location of TMD along the height of building | TMD2 | Tuned mass damper at 7th story of the residential building |
| | TMD3 | Tuned mass damper at 5th story of the residential building |
| Based on change in location of TMD in the plan projection of building. | TMD@1 | Tuned mass damper at Centre of top story in residential building |
| | TMD@2 | Tuned mass damper at eccentric distance of top story in residential building |
| | TMD@3 | Tuned mass damper at eccentric distance sof top story in residential building |

### A. *Structural Details*

The work is such that the reinforced concrete beams, columns, slabs, infill walls, and stairs were assigned to model G+8 storey building. These structures were designed in a 'H' form with plan dimensions of 21.2 m x 28.4 m. According to IS: 1893(Part I):2016, they are loaded with Dead, Live, and Seismic Forces. The time history approach is then used to examine these models for India's seismic zone V (Zone Factor = 0.36). The modelled building's specifications are provided below. With SMRF (Response Reduction Factor, R=5) and Importance Factor (I) =1, a modal damping of 5% is calculated. The performance of the models is recorded using ETABS in order to give a quick overview of the role of tuned mass dampers in earthquake protection.

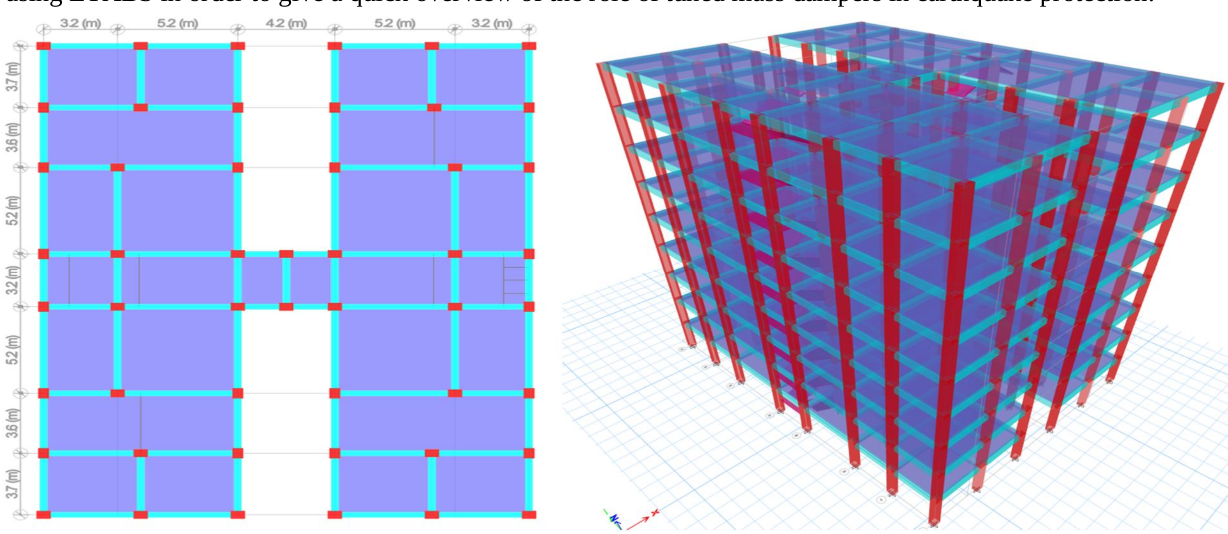



Fig. 3 (a) Plan view of G+8 Residential building model (b) Isometric view of (G+ 8) Residential building model

The following assumptions were made before the start of the modeling procedure so as to maintain similar conditions for both the models:

*1)* Only the main block of the building is considered. The staircases are not considered in the design procedure.
*2)* In this building, the main concentration is on response of the frame, as it is a residential building.
*3)* At ground floor, slabs are not provided and the floor is resting directly on the ground.
*4)* The beams are resting centrally on the columns so as to avoid the conditions of eccentricity. This is achieved automatically in ETABS.
*5)* For all structural elements, M 25 & Fe 415 is used.
*6)* The footings are not designed. Supports are assigned in the form of fixed supports.
*7)* Seismic loads are considered in the horizontal direction only (X & Y) and the loads in vertical direction (Z) are assumed to be insignificant.
*8)* Unit weight of concrete and brick are 25 $\text{kN}/m^3$ and 18 $\text{kN}/m^3$ respectively.
*9)* The size of columns and beams are 0.45 m × 0.60 m and 0.30 m × 0.5 m respectively.

### *B. Time History Functions*

The time history data used for the analysis is CORRALIT. This earthquake was actually occurred in California, USA in 1963. The data file of acceleration with respect to time is collected from the out-sourcing government websites such as PEER, COSMOS. This data is collected from the COSMOS earthquake databases. The ground motion characteristic of earthquake used of the study is given below-

Table 2 Ground Motion Characteristics

| Year | Event | Magnitude | PSA Horizontal 1 | PSA Horizontal 2 | PSA Vertical | Distance (Km) |
|---|---|---|---|---|---|---|
| 1923 | Corralito | 6.9 | 0.64 | 0.48 | 0.46 | 3.9 |

There are three components of Corralito from which only two horizontal direction acceleration data is utilized i.e., Corralito-1 and Corralito -2. The Corralito earthquake occurred around a time period of 40 seconds noted by nearest station by accelerogram. These two horizontal components are basically direction North-south-east-west from which the seismic force occurred. This is been applied in our asymmetry reference case model for the nun-linear time history analysis for more accurate results.

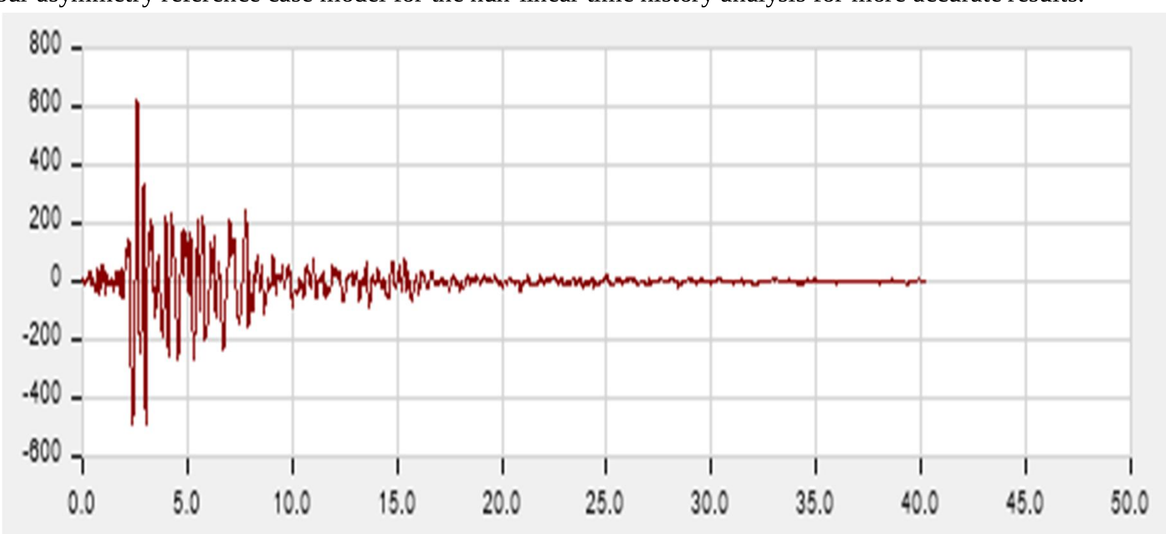


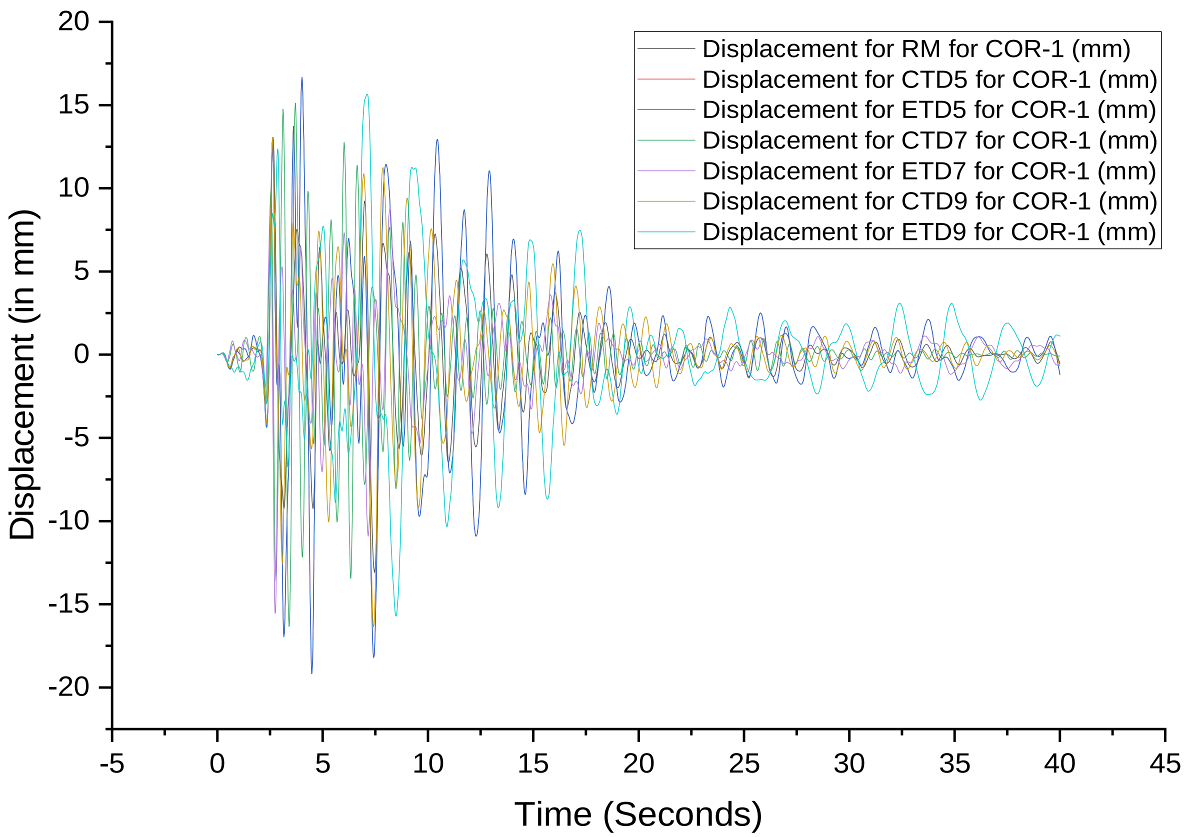

Fig. 4 Time History -Acceleration Graph of Corralito Earthquake

## V. RESULTS AND DISCUSSIONS

To determine story displacement time history analysis in x and y direction are to be done of a building without TMD and also with TMD for a particular mode and graph plotted to compare the reduction in responses for different modes also for different mass ratio peak story displacement are determine and graph also plotted for them to show the effect of mass variation.

Table 3 Displacement Report for Corralito-1 Ground Motion

| Storey | Displacement for RM (mm) | Displacement for CTD5 (mm) | Displacement for CTD7 (mm) | Displacement for CTD9 (mm) | Displacement for ETD5 (mm) | Displacement for ETD7 (mm) | Displacement for ETD9 (mm) |
|---|---|---|---|---|---|---|---|
| Storey9 | 13.071 | 12.886 | 15.123 | 1.274 | 16.67 | 15.99 | 15.657 |
| Storey8 | 12.114 | 9.644 | 9.216 | 4.108 | 12.327 | 14.108 | 15.87 |
| Storey7 | 10.777 | 6.269 | 3.594 | 7.408 | 9.526 | 12.658 | 16.084 |
| Storey6 | 9.177 | 3.777 | 5.81 | 10.997 | 7.668 | 12.446 | 15.446 |
| Storey5 | 7.541 | 3.283 | 9.889 | 13.006 | 7.449 | 11.567 | 13.626 |
| Storey4 | 5.938 | 6.693 | 12.021 | 11.84 | 5.969 | 9.909 | 10.993 |
| Storey3 | 4.4 | 9.415 | 11.232 | 8.434 | 4.874 | 8.896 | 8.1 |
| Storey2 | 2.859 | 8.238 | 7.894 | 5.201 | 4.094 | 6.029 | 5.166 |
| Storey1 | 1.195 | 3.601 | 3.199 | 1.959 | 3.395 | 2.301 | 1.941 |




## VI. CONCLUSIONS

The percentage response reduction is maximum to nearer stories where tuned mass damper is installed. It has been seen that the storey deformation in damped structure is less as compared to the conventional building frame. Application of the damper at the centroidal is more effective than at the eccentric location in terms of displacement.

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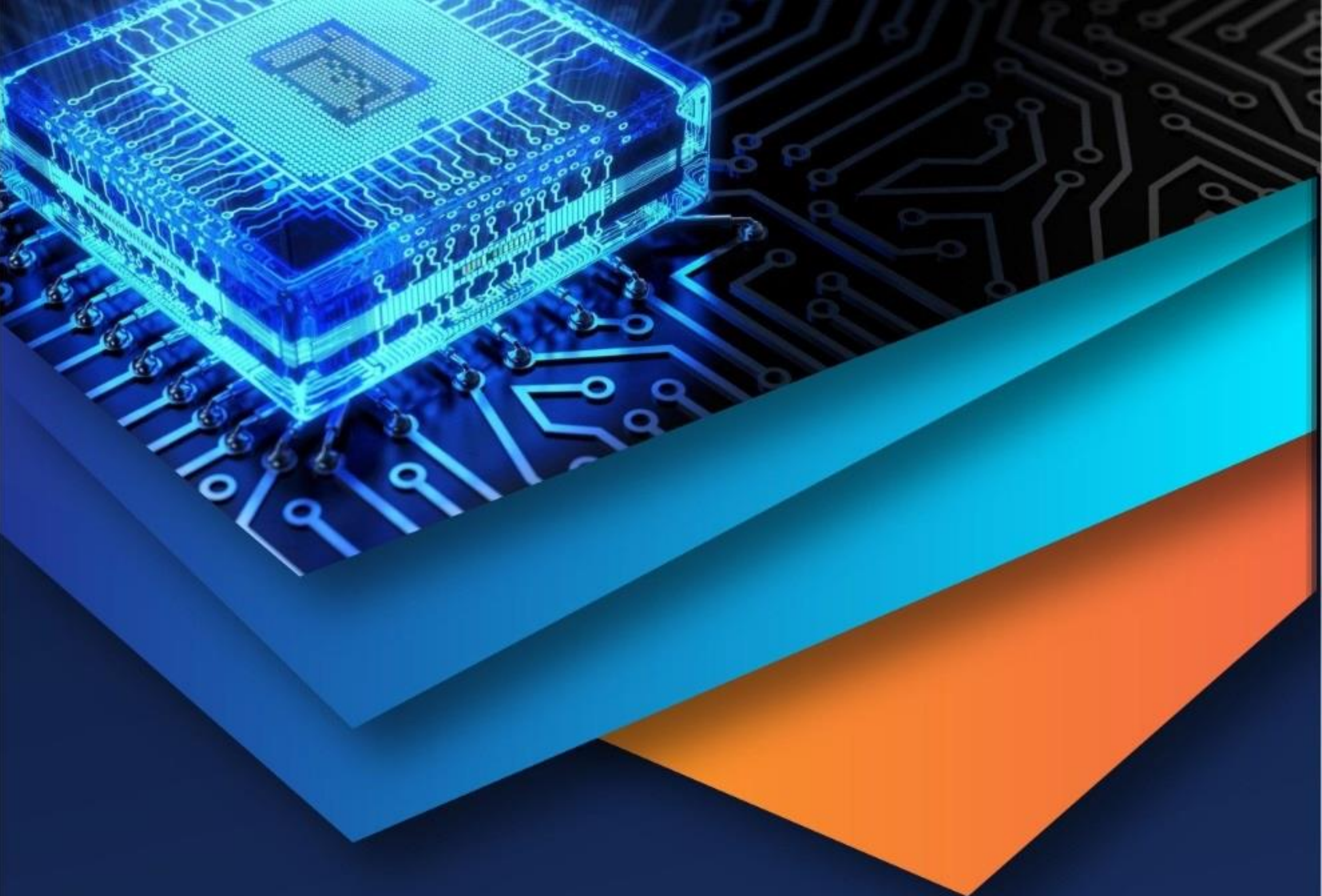


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