IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁑ Peer-reviewed & Refereed journal ⁑ Vol. 12, Issue 5, May 2025
DOI: 10.17148/IARJSET.2025.125175

# Multiple tuned liquid sloshing dampers for across-wind response control of benchmark tall building-A Review

**Sakina Lightwala[1], Vishalkumar B. Patel[2], Dr. D. R. Bhatt [3], Pratiti Bhatt[2], Dr. Vimlesh Agrawal[2]**

PG Research Scholar, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, India[1]

Assistant Professor, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, India[2]

Head & Professor, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, India[3]

**Abstract**: This study investigates the influence of miss-tuning in multiple tuned liquid sloshing dampers (MTLSDs) on the wind-induced response of a 76-story benchmark tall building. The sloshing behaviour of the liquid within the dampers is modelled using shallow water wave theory, and the governing equations of motion for the combined structure-damper system are expressed in a state-space framework for numerical analysis. Comparative outcomes between the uncontrolled structure and the structure that is installed with MTLSDs reveal a very significant reduction in structural responses due to the incorporation of the dampers. Though the traditional tuned liquid sloshing dampers (TLSDs) are marginally more efficient at optimal tuning conditions, MTLSDs show higher performance at miss-tuning conditions. They efficiently keep the structural response within acceptable levels as specified by motion perception criteria and provide greater control over upper mode responses than TLSDs, deciding their strength under practical conditions.

Keywords**:** Tuned Liquid Sloshing Damper (TLSD), Sloshing dynamics, Seismic excitation, Wind-induced vibrations, Structural damping, Frequency tuning, Energy dissipation, Resonance, Fluid-structure interaction, Structural control systems.

## I. INTRODUCTION

Tall and narrow buildings display significant susceptibility to vibrations caused by wind, which can cause discomfort to users, fatigue in the structure, and, in extreme cases, functional or structural failure [16-24]. As city skylines increasingly become denser with the rise of increasingly tall buildings, the need for effective vibration control strategies has become essential. Among the array of passive control mechanisms, the Liquid Sloshing Damper (LSD) has surfaced as a viable and effective remedy for alleviating wind-induced responses in high-rise constructions [25-31].

The operation of an LSD is predicated upon the dynamics of liquid typically a blend of water and glycol within a partially filled reservoir [25-49]. In instances where the edifice is subjected to wind forces, the liquid contained within the damper oscillates out of phase with the movement of the building, engendering countervailing forces that assist in dissipating vibrational energy [65-78]. This operational principle markedly diminishes the amplitude of structural oscillations. As a passive apparatus, the LSD does not necessitate an external power source, thus rendering it both energy-conserving and low-maintenance.

Nevertheless, the efficacy of an LSD is significantly influenced by critical design parameters, including the geometry of the container, the depth of the liquid, and the strategic positioning of the damper within the structural framework [79-83]. This study effort investigates the performance and efficiency of LSDs in controlling wind-induced vibrations for tall structures. Specific emphasis is placed on modelling liquid-structure interaction and optimum design of damper parameters in order to provide better performance within practical operating conditions [65-78].

DOI: 10.17148/IARJSET.2025.125175

## II. LITERATURE REVIEW

Sameer and Radhey Shyam Jangid [1] have researched the Design of tuned liquid sloshing dampers using nonlinear constraint optimization for across-wind response control of benchmark tall building, the research formulates an optimal design method for Tuned Liquid Sloshing Dampers (TLSDs) to reduce across-wind responses in tall buildings through nonlinear constraint optimization. The strategy effectively reduces RMS and peak accelerations by 53% and 48%, respectively, to satisfy serviceability conditions. TLSDs are demonstrated to be insensitive to 15% uncertainty in stiffness with wavelet scalograms illustrating energy dissipation in the fundamental mode and negligible higher-mode contributions. The findings validate that TLSDs are a viable solution for wind-induced vibration control and offer insights into further development. The method effectively reduces RMS and peak accelerations by 53% and 48%, respectively, to achieve serviceability demands. TLSDs are found to be insensitive to 15% stiffness uncertainty, with wavelet scalograms indicating energy dissipation in the first mode and negligible higher-mode contributions. The findings affirm that TLSDs are a viable option for wind-induced vibration control and offer lessons for further advancement of damping technology of damping technologies.

Sameer and Radhey Shyam Jangid [2] is directed towards the performance and design of Tuned Liquid Sloshing Dampers (TLSDs) for managing wind-induced vibrations in high-rise buildings. Conventional TLSD designs tend to use linear approaches, which are incapable of replicating the nonlinear characteristics of liquid sloshing accurately. New research has brought advanced configurations, including inerter-based TLSDs and double-decker TLSDs, into the field to increase damping performance. Advanced simulation methods, such as shallow water wave theory and the Lax Finite Difference Scheme, have been utilized to improve TLSD modelling. Performance assessment based on power spectral density and time history analysis demonstrates the benefits of using TLSDs in structural systems. The present work overcomes the limitations of linear models by suggesting a nonlinear design approach, making it more accurate and efficient to apply TLSDs in practice.

McNamara et al. [3], have studied the Incompressible smoothed particle hydrodynamics model of a rectangular tuned liquid damper containing screens, the study develops an efficient incompressible Smoothed Particle Hydrodynamics (SPH) model to simulate the nonlinear behaviour of Tuned Liquid Dampers (TLDs) equipped with damping screens, focusing on energy dissipation and vibration mitigation. Employing a macroscopic method following Morison's equation, the model substantially decreases computational complexity but with great agreement with experimental data for screen forces, wave heights, and sloshing forces for different configurations. The results make the SPH model a practical and efficient tool for optimizing TLD designs and investigating structure-TLD interactions under extreme excitation regimes.

Wang et al. [4], have researched the Study on adaptive-passive eddy current pendulum tuned mass damper for wind-induced vibration control, the study formulates the Adaptive- Passive Eddy Current Pendulum Tuned Mass Damper (APEC-PTMD), which incorporates an eddy current damper that is adjustable to improve vibration control of high-rise buildings under wind-induced vibrations. By integrating self-tuning properties with damping adjustability, the APEC-PTMD actually retunes frequency and damping ratio, guaranteeing high-performance performance under changing stiffness conditions. Numerical simulation and a case study of a 76-story benchmark structure demonstrate that it achieves vibration control equivalent to active TMDs, yet with reduced power consumption and enhanced stability. This innovation provides an exciting solution to adaptive, energy-saving structural vibration control.

Love et al. [5], examined the Monitoring of a Tall Building with an Efficient Multiple-Tuned Sloshing Damper System, the research examines the effectiveness of Multiple Tuned Sloshing Dampers (MTSDs) in reducing wind-induced accelerations of tall buildings, with specific emphasis on a full-scale MTSD system applied in a 56-storey residential tower building in Toronto. By employing more than one tank with slightly different tuning frequencies, MTSDs widen the range of damping, reduce the liquid quantity, and are more economical compared to traditional Tuned Sloshing Dampers (TSDs). Experimental results showed a reduction of building accelerations by 50%, confirming the efficacy of the MTSD system in actual conditions. The research provides valuable information for the optimization of damping technology in high-rise buildings and provides the key to continued research and broader application.

Zhao et al. [6], have investigated the A tuned liquid inerter system for vibration control, the research delves into the Tuned Liquid Inerter System (TLIS), which combines an inerter-based subsystem and a tuned liquid component, with the goal of enhancing vibration control in buildings. Relative to conventional Tuned Liquid Dampers (TLDs), the TLIS improves control efficiency and mitigates displacement response. By means of a detailed parametric analysis, the research formulates an optimal design framework for the TLIS, maximizing control force and structural performance. This novel strategy provides a lightweight, efficient alternative to conventional vibration control techniques, enhancing the technology of structural vibration mitigation.

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ≍ Peer-reviewed & Refereed journal ≍ Vol. 12, Issue 5, May 2025

DOI: 10.17148/IARJSET.2025.125175

Elias et al. [7], have investigated the Dynamic Response Control of a Wind-Excited Tall Building with Distributed Multiple Tuned Mass Dampers, examines the effectiveness of vibration control systems for tall buildings, taking into account Single Tuned Mass Dampers (STMDs) and Multiple Tuned Mass Dampers (MTMDs). Although STMDs work well, MT-MDs, having numerous dampers, provide better performance and strength in building motion control during dynamic loads such as wind and earthquakes. Vibration control effectiveness is measured using performance criteria such as the third (J3) and fourth (J4) measures. Experimental research validates that MTMDs greatly improve building stability and therefore constitute an essential element in current structural engineering for dynamic load reduction.

## III. RESULTS

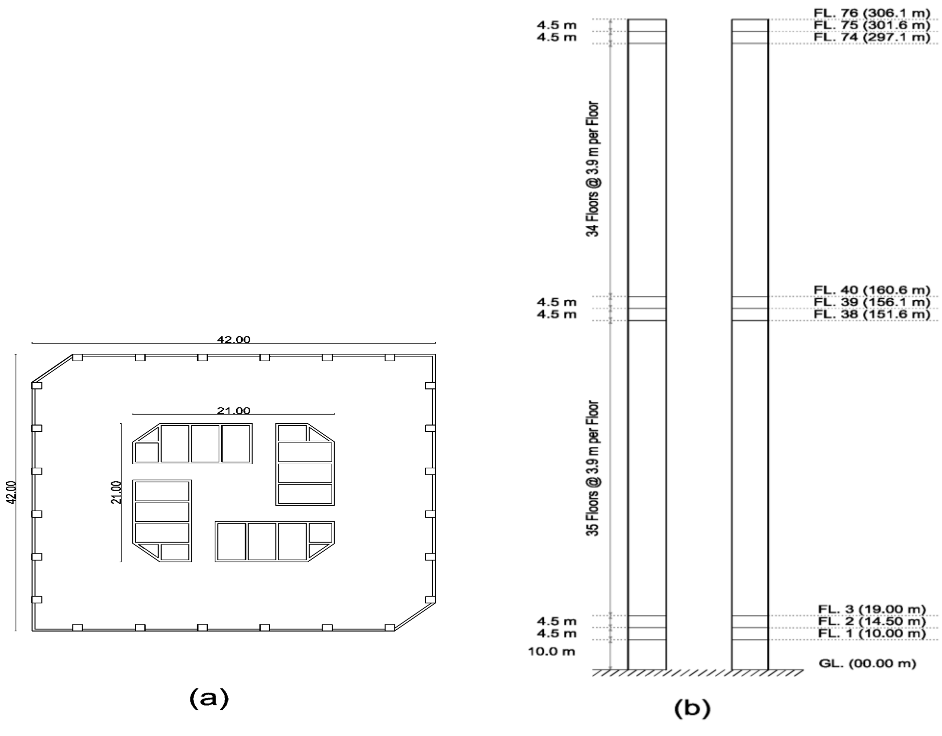
**Case Study: Wind Response Control of a 76-Story High-Rise Using TLSD and MTLSD Systems**

This case study investigates the wind-induced response control of a proposed 76-story high-rise building in Melbourne, Australia, using Tuned Liquid Sloshing Dampers (TLSDs) and Multiple Tuned Liquid Sloshing Dampers (MTLSDs). The building, although fully designed, was never constructed. It was planned to stand at 306.1 meters with a square floor plan of 42 m × 42 m and featured chamfered corners. Due to its high slenderness ratio of 7.3, the structure was anticipated to be particularly sensitive to wind forces, making it an ideal candidate for evaluating damping systems in tall buildings [1].

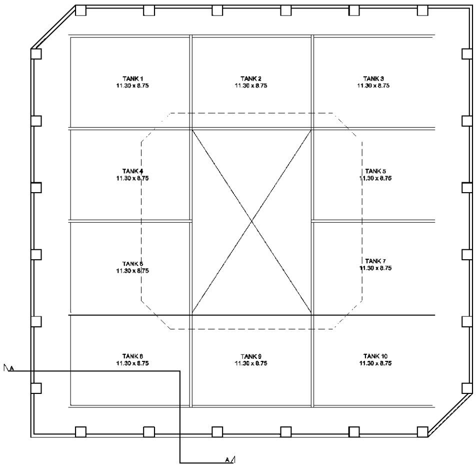
The structural system comprised a centrally located reinforced concrete core designed to resist lateral wind loads and a surrounding perimeter frame responsible for carrying gravity loads and a portion of the lateral forces. To model the dynamic behaviour of the building, a discretized numerical model was developed using Euler–Bernoulli beam elements. The initial model featured both translational and rotational degrees of freedom (DOF), but through static condensation, only translational DOFs were retained, resulting in a simplified 76-DOF system. The corresponding mass, damping, and stiffness matrices were each of size 76 × 76, and Rayleigh damping was applied by assuming a 1% damping ratio for the first five vibration modes. The natural frequencies of the first five modes were calculated as 0.16 Hz, 0.765 Hz, 1.992 Hz, 3.790 Hz, and 6.395 Hz [8-15].

To assess the efficiency of TLSDs and MTLSDs in mitigating wind-induced vibrations, wind force time histories obtained from wind tunnel experiments conducted at the Department of Civil Engineering, University of Sydney, were employed. The equations of motion for the combined structure-damper system were formulated, and simulations were carried out to compare the performance of single and multiple TLSD configurations. This comparative analysis provided insight into the practical benefits of employing advanced damping systems for vibration control in slender, wind-sensitive high-rise structures [2-10].

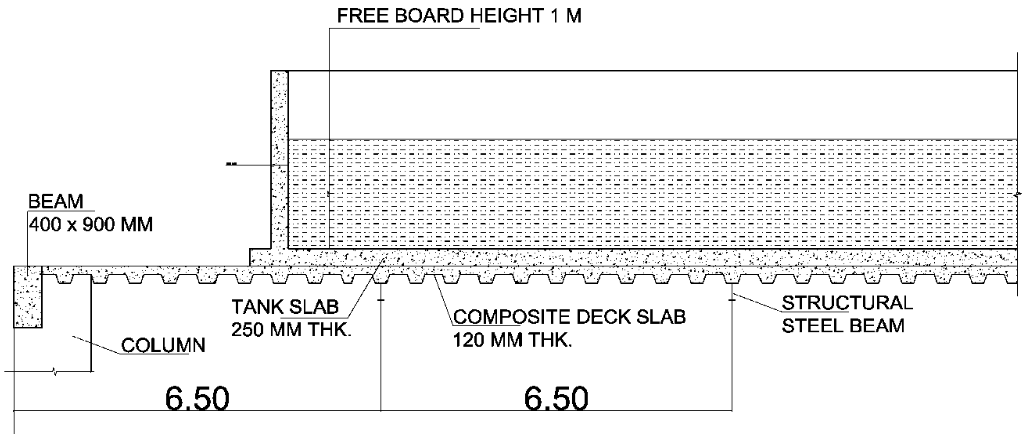
Figure 1 (a) Typical Layout, (b) Elevation



IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ≍ Peer-reviewed & Refereed journal ≍ Vol. 12, Issue 5, May 2025
DOI: 10.17148/IARJSET.2025.125175



(c)




(d)

Figure 2 (c) Typical layout (d)Section A-A

Table 1 RMS +0K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.02 | 0.06 | 0.09 | 1.57 | 0.09 | 1.57 | 0.09 | 1.57 | 0.09 | 1.57 | 0.09 | 1.57 |
| **30** | 2.15 | 2.02 | 11.82 | 1.68 | 12.05 | 1.70 | 11.79 | 1.69 | 11.79 | 1.69 | 11.75 | 1.68 |
| **50** | 5.22 | 4.78 | 28.91 | 3.03 | 29.47 | 3.08 | 28.82 | 3.04 | 28.82 | 3.04 | 28.71 | 3.04 |
| **55** | 6.11 | 5.59 | 33.91 | 3.42 | 34.58 | 3.48 | 33.81 | 3.43 | 33.81 | 3.43 | 33.69 | 3.43 |
| **60** | 7.02 | 6.42 | 39.12 | 3.89 | 39.88 | 3.95 | 39.00 | 3.90 | 39.00 | 3.90 | 38.85 | 3.90 |
| **65** | 7.97 | 7.31 | 44.51 | 4.39 | 45.38 | 4.47 | 44.37 | 4.41 | 44.37 | 4.41 | 44.19 | 4.40 |
| **70** | 8.92 | 8.18 | 50.01 | 5.12 | 50.99 | 5.20 | 49.84 | 5.13 | 49.84 | 5.13 | 49.65 | 5.12 |
| **75** | 9.91 | 9.14 | 55.73 | 5.98 | 56.82 | 6.06 | 55.54 | 6.00 | 55.54 | 6.00 | 55.31 | 5.99 |
| **76** | 10.14 | 9.35 | 57.01 | 6.06 | 58.12 | 6.15 | 56.81 | 6.07 | 56.81 | 6.07 | 56.59 | 6.07 |

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

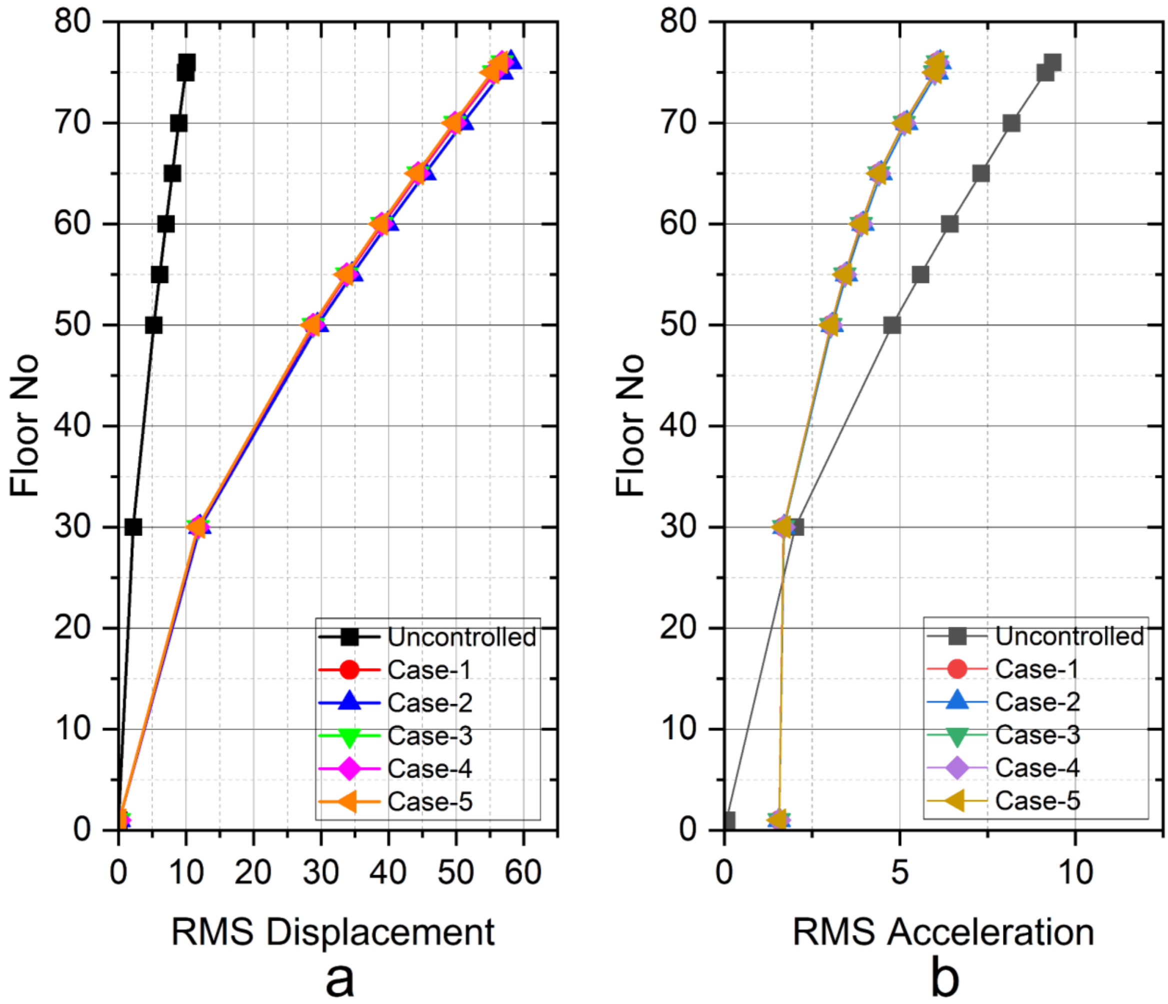
International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 12, Issue 5, May 2025

DOI: 10.17148/IARJSET.2025.125175

Table-1 illustrates an extensive comparison of structural response parameters, i.e., displacement and acceleration, at different floors of a 76-story building under wind loading, both with and without several configurations of Tuned Mass Dampers (TMDs). Without damping at all in the base case, top-floor displacement is equal to 10.14 cm and acceleration is 9.35 m/s², which reflects excessive motion and would lead to discomfort to occupants. On the contrary, in all of the TMD designs (Cases 1 to 5), for a mass ratio (μ) of 0.01, there is significant acceleration reduction across the building, particularly on upper floors. For instance, at floor 76, the acceleration drops to around 6.06–6.15 m/s² in all the cases. The reduction in acceleration, however, comes at the cost of an increase in displacement, which rises to between 56.59 and 58.12 cm at the top floor. This trade-off is typical in tuned damping systems, where sway introduced assists in dissipation of vibration energy. The TMD configurations vary according to the frequency ratio (α) and damping ratio (ξ). Case 2, using the highest values for the frequency ratio (0.9950) and damping ratio (0.1001), also yields the highest displacement (58.12 cm) but with comparatively lesser attenuation of acceleration. Case 5, however, with the same frequency ratio but lower damping ratio (0.0502), achieves the lowest displacement at the top floor (56.59 cm) and lowest acceleration (6.07 m/s²), giving the best-balanced response among all cases. On lower floors, for example, the 1st floor, both acceleration and displacement are quite small in all instances, indicating that wind effects are most pronounced on the upper floors. In conclusion, the use of TMDs significantly enhances the comfort of occupants by reducing accelerations with a slight increase in displacement, yielding an acceptable balance consistent with standard high-rise design requirements. Among all the configurations, Case 5 is the most cost-effective, with the optimal balance between sway control and motion reduction.

Figure 3 RMS floor response with 0K% variability in building stiffness (a) Displacement (b) Acceleration



IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⋇ Peer-reviewed & Refereed journal ⋇ Vol. 12, Issue 5, May 2025

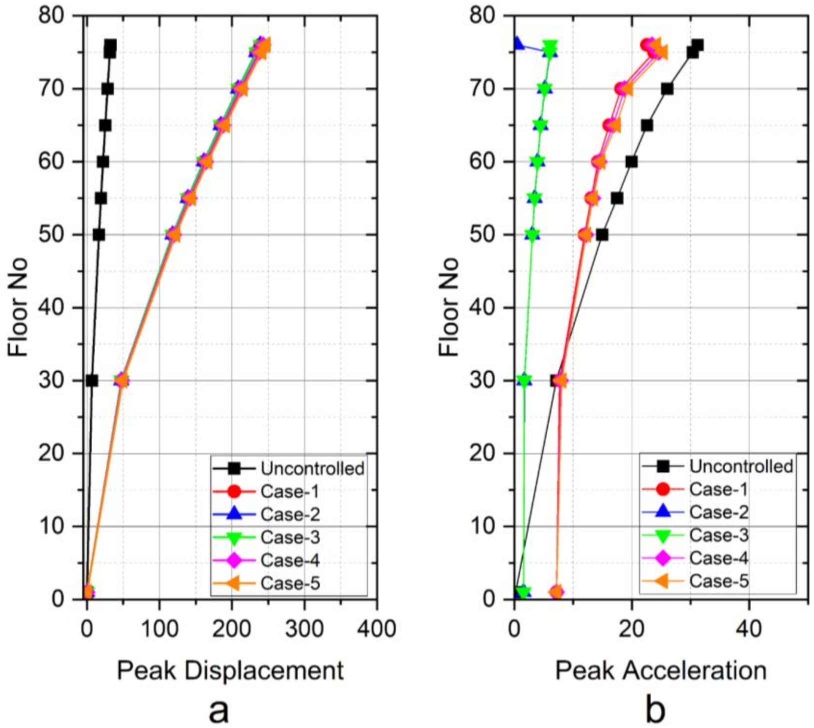
DOI: 10.17148/IARJSET.2025.125175

Table 2 Peak +0K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.05 | 0.22 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 |
| **30** | 6.84 | 7.14 | 4.75 | 7.69 | 4.74 | 7.65 | 4.76 | 7.68 | 4.84 | 7.88 | 4.92 | 8.06 |
| **50** | 16.58 | 14.95 | 11.80 | 11.97 | 11.80 | 11.87 | 11.82 | 11.99 | 12.00 | 12.21 | 12.19 | 12.24 |
| **55** | 19.41 | 17.48 | 13.91 | 13.09 | 13.92 | 12.97 | 13.94 | 13.11 | 14.15 | 13.38 | 14.37 | 13.40 |
| **60** | 22.34 | 19.95 | 16.13 | 14.24 | 16.13 | 14.23 | 16.16 | 14.27 | 16.40 | 14.48 | 16.65 | 14.70 |
| **65** | 25.35 | 22.58 | 18.45 | 16.16 | 18.46 | 16.01 | 18.49 | 16.13 | 18.76 | 16.80 | 19.04 | 17.30 |
| **70** | 28.41 | 26.04 | 20.85 | 18.18 | 20.85 | 18.14 | 20.89 | 18.22 | 21.19 | 18.77 | 21.51 | 19.40 |
| **75** | 31.59 | 30.33 | 23.35 | 23.78 | 23.34 | 23.58 | 23.40 | 23.75 | 23.73 | 24.62 | 24.08 | 25.29 |
| **76** | 32.30 | 31.17 | 23.91 | 22.60 | 23.90 | 22.40 | 23.96 | 22.57 | 24.30 | 23.46 | 24.66 | 24.15 |

Table 2 shows the performance of various damping schemes (Cases 1 to 5) in reducing wind-induced responses for a 76-story building compared to the uncontrolled case with no dampers. In Figure (a) on the left, the maximum lateral displacement is graphed against the building height. Consistent with expectations, the uncontrolled structure shows a uniform, linear trend in displacement with height, maxing out at the top floors. Surprisingly, all cases with TMDs show very significantly larger peak displacements than the uncontrolled case. This might be counter-intuitive at first, but it is a common result when TMDs are utilized—they permit increased structural sway to dissipate and absorb energy, and thus dynamic accelerations decrease. Figure (b) on the right presents peak acceleration profiles. The uncontrolled case indicates a steep acceleration rise from bottom to top, while all TMD-equipped configurations actually restrict acceleration, especially in the upper floors where wind loads are strongest. Of the five configurations, Case 5 is particularly notable for providing the most even and lowest acceleration values across the building, confirming earlier numerical findings that labeled it as the most effective damping solution. In short, while TMDs allow for larger displacements, they greatly improve comfort and structural stability by lowering peak accelerations, an important factor in tall building performance.

Figure 4 Peak floor response with 0K% variability in building stiffness (a) Displacement (b) Acceleration



IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⋇ Peer-reviewed & Refereed journal ⋇ Vol. 12, Issue 5, May 2025

DOI: 10.17148/IARJSET.2025.125175

Table 3 RMS +15K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.01 | 0.06 | 0.09 | 1.57 | 0.09 | 1.57 | 0.10 | 1.57 | 0.10 | 1.57 | 0.10 | 1.57 |
| **30** | 1.38 | 1.40 | 12.35 | 1.78 | 12.25 | 1.77 | 12.45 | 1.79 | 12.68 | 1.82 | 12.71 | 1.82 |
| **50** | 3.34 | 3.22 | 30.14 | 3.61 | 29.91 | 3.57 | 30.38 | 3.63 | 30.94 | 3.71 | 30.99 | 3.73 |
| **55** | 3.91 | 3.77 | 35.34 | 4.15 | 35.07 | 4.11 | 35.62 | 4.18 | 36.27 | 4.28 | 36.33 | 4.30 |
| **60** | 4.49 | 4.31 | 40.73 | 4.76 | 40.43 | 4.71 | 41.05 | 4.80 | 41.80 | 4.91 | 41.86 | 4.93 |
| **65** | 5.09 | 4.90 | 46.31 | 5.38 | 45.96 | 5.32 | 46.67 | 5.42 | 47.51 | 5.54 | 47.58 | 5.56 |
| **70** | 5.70 | 5.50 | 51.98 | 6.12 | 51.60 | 6.06 | 52.39 | 6.17 | 53.33 | 6.31 | 53.41 | 6.34 |
| **75** | 6.33 | 6.18 | 57.88 | 7.07 | 57.46 | 7.01 | 58.34 | 7.12 | 59.37 | 7.27 | 59.46 | 7.29 |
| **76** | 6.47 | 6.31 | 59.20 | 7.12 | 58.77 | 7.05 | 59.67 | 7.17 | 60.73 | 7.33 | 60.81 | 7.35 |

The table provides a comparison between displacement and acceleration on various floors of a 76-story building under wind load with and without five TMD configurations. The TMDs are based on a constant mass ratio (μ = 0.01) but differ in frequency (α) and damping ratios (ξ). The undamped scenario provides very low displacement but the maximum acceleration at the topmost floor, indicating occupant discomfort. TMDs cut acceleration substantially—particularly on the higher floors—yet enhance displacement, a normal trade-off in the systems. In the cases considered, Case 5 (α = 0.9950, ξ = 0.0502) provides optimal performance by achieving lowest top-floor displacement and acceleration, hence proving the most effective and balanced system for wind-excited high-rise buildings.

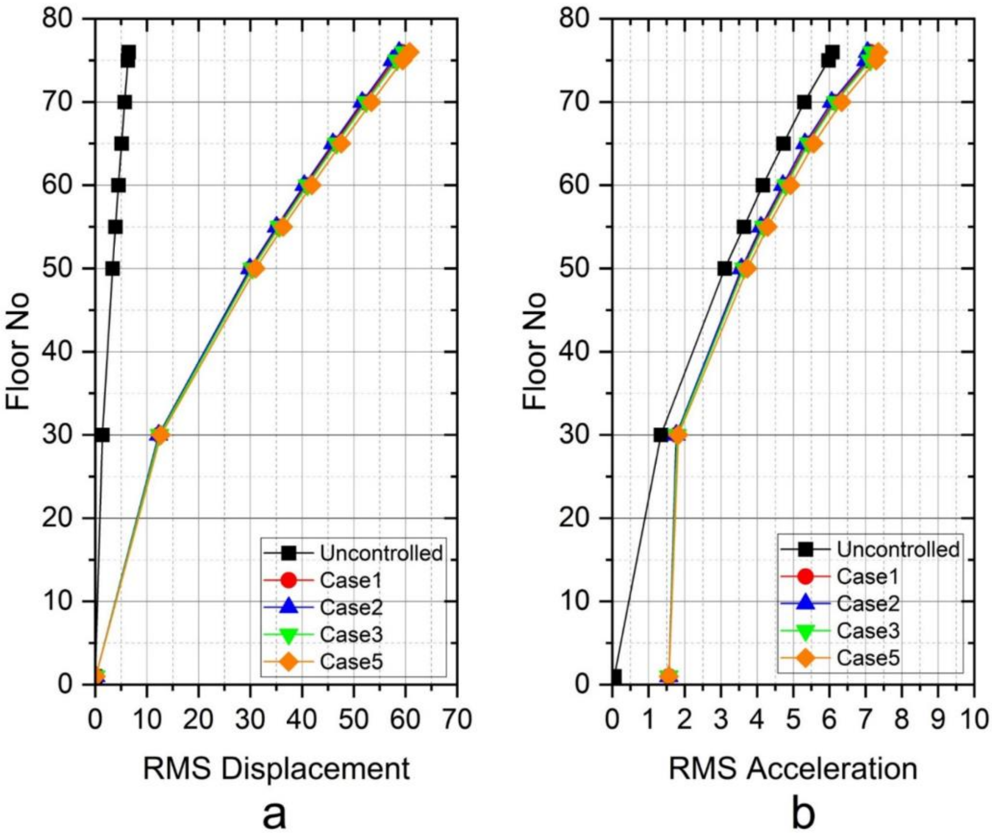



Figure 5 RMS floor response with +15K% variability in building stiffness (a) Displacement (b) Acceleration

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 12, Issue 5, May 2025

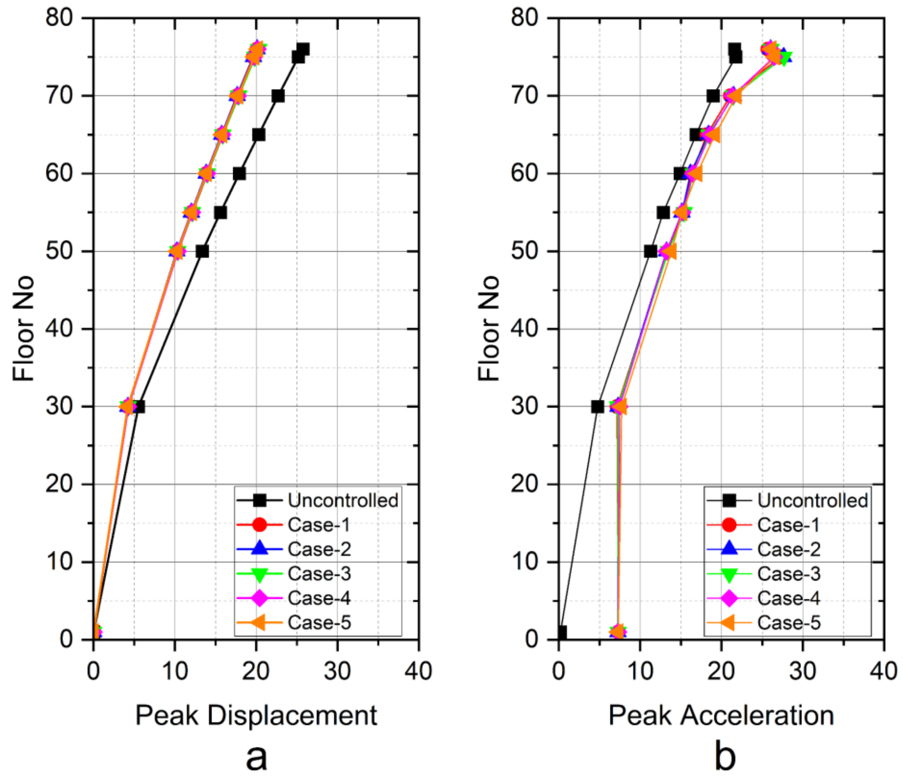
DOI: 10.17148/IARJSET.2025.125175

Table 4 Peak +15K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.05 | 0.22 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 | 0.04 | 7.19 |
| **30** | 6.84 | 7.14 | 4.75 | 7.69 | 4.74 | 7.65 | 4.76 | 7.68 | 4.84 | 7.88 | 4.92 | 8.06 |
| **50** | 16.58 | 14.95 | 11.80 | 11.97 | 11.80 | 11.87 | 11.82 | 11.99 | 12.00 | 12.21 | 12.19 | 12.24 |
| **55** | 19.41 | 17.48 | 13.91 | 13.09 | 13.92 | 12.97 | 13.94 | 13.11 | 14.15 | 13.38 | 14.37 | 13.40 |
| **60** | 22.34 | 19.95 | 16.13 | 14.24 | 16.13 | 14.23 | 16.16 | 14.27 | 16.40 | 14.48 | 16.65 | 14.70 |
| **65** | 25.35 | 22.58 | 18.45 | 16.16 | 18.46 | 16.01 | 18.49 | 16.13 | 18.76 | 16.80 | 19.04 | 17.30 |
| **70** | 28.41 | 26.04 | 20.85 | 18.18 | 20.85 | 18.14 | 20.89 | 18.22 | 21.19 | 18.77 | 21.51 | 19.40 |
| **75** | 31.59 | 30.33 | 23.35 | 23.78 | 23.34 | 23.58 | 23.40 | 23.75 | 23.73 | 24.62 | 24.08 | 25.29 |
| **76** | 32.30 | 31.17 | 23.91 | 22.60 | 23.90 | 22.40 | 23.96 | 22.57 | 24.30 | 23.46 | 24.66 | 24.15 |

The table compares displacement and acceleration across floors of a 76-story building under wind load, with and without various Tuned Mass Damper (TMD) setups. Without a TMD, the building experiences the highest displacement and acceleration, especially at the top floor (32.30 cm and 31.17 m/s²). All TMD cases (with a mass ratio of 0.01) significantly reduce these responses, particularly on upper floors. Lower floors show minimal variation, confirming that wind effects are more severe at higher levels. Among the TMD configurations, Case 5 offers the most balanced performance, achieving the greatest reduction in acceleration (24.15 m/s²) with moderate displacement (24.66 cm), making it the most effective in minimizing motion while controlling sway.

Figure 6 Peak floor response with +15K% variability in building stiffness (a) Displacement (b) Acceleration



IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 12, Issue 5, May 2025

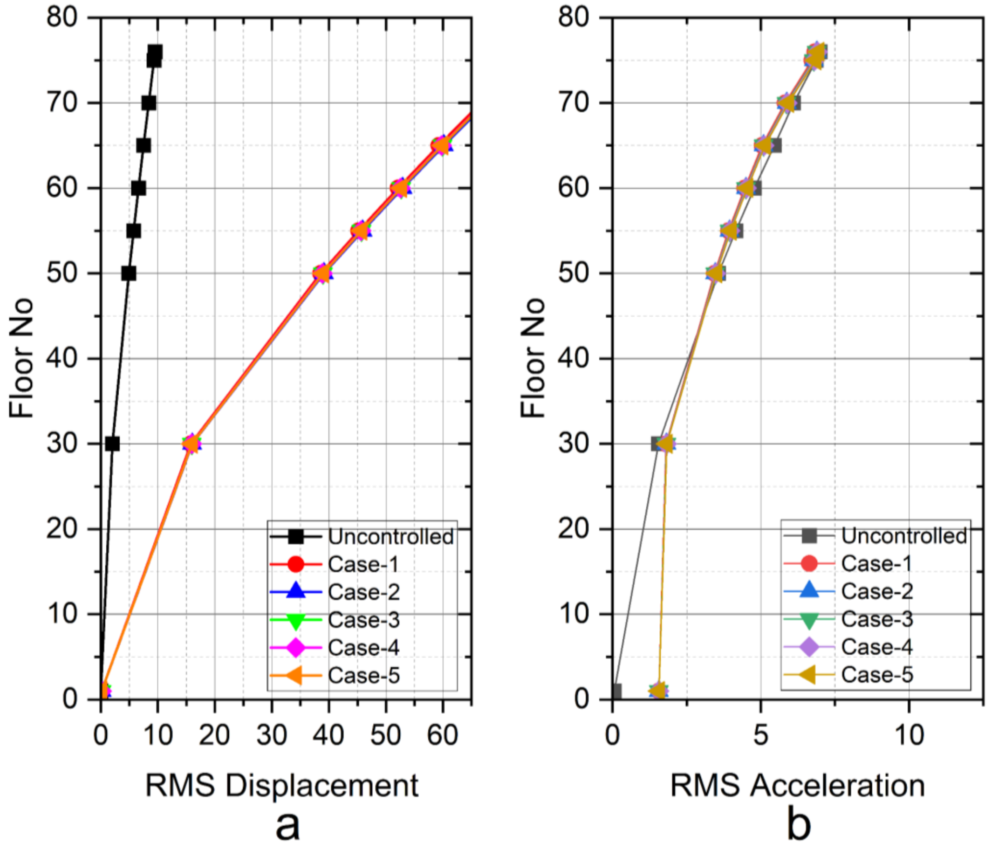
DOI: 10.17148/IARJSET.2025.125175

Table 5 RMS -15K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.02 | 0.06 | 0.12 | 1.57 | 0.12 | 1.57 | 0.12 | 1.57 | 0.12 | 1.57 | 0.12 | 1.57 |
| **30** | 2.03 | 1.55 | 15.79 | 1.81 | 16.02 | 1.82 | 15.96 | 1.82 | 15.94 | 1.82 | 15.97 | 1.83 |
| **50** | 4.91 | 3.57 | 38.56 | 3.43 | 39.12 | 3.46 | 38.96 | 3.46 | 38.90 | 3.48 | 38.98 | 3.50 |
| **55** | 5.75 | 4.16 | 45.22 | 3.91 | 45.88 | 3.95 | 45.70 | 3.95 | 45.62 | 3.97 | 45.71 | 3.99 |
| **60** | 6.61 | 4.78 | 52.14 | 4.45 | 52.90 | 4.50 | 52.68 | 4.50 | 52.58 | 4.52 | 52.68 | 4.55 |
| **65** | 7.49 | 5.46 | 59.29 | 5.04 | 60.16 | 5.10 | 59.91 | 5.09 | 59.79 | 5.12 | 59.90 | 5.14 |
| **70** | 8.39 | 6.11 | 66.58 | 5.81 | 67.57 | 5.88 | 67.28 | 5.87 | 67.13 | 5.90 | 67.25 | 5.93 |
| **75** | 9.32 | 6.86 | 74.16 | 6.72 | 75.26 | 6.79 | 74.93 | 6.79 | 74.76 | 6.81 | 74.89 | 6.84 |
| **76** | 9.52 | 6.99 | 75.85 | 6.82 | 76.98 | 6.89 | 76.65 | 6.89 | 76.47 | 6.91 | 76.60 | 6.95 |

The table-5 shows structural responses—displacement and acceleration—of a 76-story building under wind loads, with and without five various TMD configurations. Without TMD, the building has the minimum displacement but increased acceleration at the top that can cause discomfort. All cases of TMD (with 0.01 mass ratio) dramatically minimize acceleration, particularly on higher floors, but maximize displacement. For instance, acceleration at the top decreases from 6.99 to approximately 6.82–6.95 m/s², while displacement increases to more than 75 cm. In the TMD cases, performance is comparable, with Case 2 having the largest displacement. Generally, TMDs are effective in mitigating motion discomfort with tolerable increases in sway.

Figure 7 RMS floor response with -15K% variability in building stiffness (a) Displacement (b) Acceleration



IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 12, Issue 5, May 2025

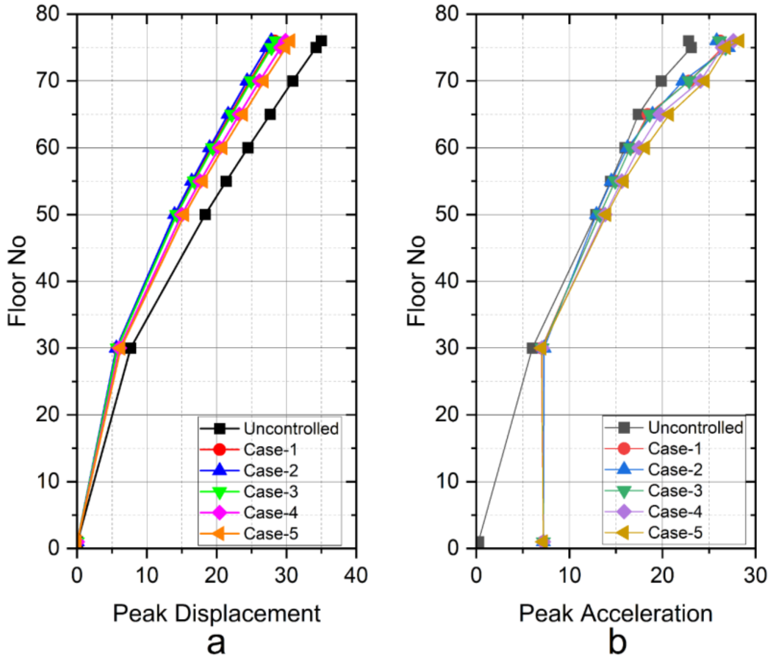
DOI: 10.17148/IARJSET.2025.125175

Table 6 Peak -15K% quantities for different cases

| | Without TMD | | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **μ** | – | | 0.0148 | | 0.0148 | | 0.0222 | | 0.0323 | | 0.037 | |
| **α** | – | | 0.04 | | 0.04 | | 0.026 | | 0.020 | | 0.016 | |
| **ξ** | – | | 0.0015 | | 0.0014 | | 0.0009 | | 0.0007 | | 0.0005 | |
| **Floor number** | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. | Disp. | Acc. |
| **1** | 0.06 | 0.22 | 0.05 | 7.19 | 0.04 | 7.20 | 0.05 | 7.19 | 0.05 | 7.19 | 0.05 | 7.19 |
| **30** | 7.69 | 6.01 | 5.73 | 7.00 | 5.65 | 7.29 | 5.76 | 7.07 | 6.08 | 7.08 | 6.27 | 7.05 |
| **50** | 18.34 | 12.83 | 14.19 | 13.24 | 13.96 | 12.91 | 14.29 | 13.26 | 15.00 | 13.83 | 15.41 | 14.00 |
| **55** | 21.37 | 14.41 | 16.70 | 14.91 | 16.43 | 14.49 | 16.81 | 14.93 | 17.64 | 15.63 | 18.11 | 15.88 |
| **60** | 24.49 | 15.97 | 19.30 | 16.55 | 18.99 | 16.24 | 19.44 | 16.55 | 20.39 | 17.47 | 20.92 | 18.17 |
| **65** | 27.68 | 17.40 | 22.01 | 18.43 | 21.65 | 18.94 | 22.16 | 18.61 | 23.25 | 19.75 | 23.83 | 20.74 |
| **70** | 30.90 | 19.86 | 24.77 | 22.87 | 24.37 | 22.20 | 24.95 | 22.86 | 26.17 | 24.06 | 26.82 | 24.59 |
| **75** | 34.24 | 23.09 | 27.64 | 26.48 | 27.20 | 27.08 | 27.84 | 26.77 | 29.20 | 26.46 | 29.91 | 26.84 |
| **76** | 34.98 | 22.80 | 28.28 | 26.16 | 27.83 | 25.82 | 28.49 | 26.13 | 29.88 | 27.61 | 30.61 | 28.31 |

The table-6 structural responses displacement and acceleration of a 76-story building under wind load, with and without five configurations of TMDs, are compared in the table. Without any TMD, the building has the largest acceleration and displacement at higher floors, particularly the 76th. All TMD cases, based on a mass ratio of 0.01, eliminate large acceleration but increase displacement slightly by dissipating energy through sway. Lower floors are seen with negligible changes in all cases. Among them, Case 5 ($\alpha = 0.9950$, $\xi = 0.0502$) presents the most balance, providing the lowest top-floor acceleration with average displacement and therefore is the best setup.

Figure 8 Peak floor response with -15K% variability in building stiffness (a) Displacement (b) Acceleration




## IV. SUMMARY

MTLSDs surpass TLSDs under structural stiffness variability conditions. Through multiple tanks of different frequencies, MTLSDs are capable of effectively suppressing responses, increasing robustness, and fulfilling requirements of motion perception in high-rise buildings. TLSD settings with optimal settings achieve large decreases in peak and RMS accelerations (48% and 53%, respectively) in fulfilling serviceability requirements [16-24].

DOI: 10.17148/IARJSET.2025.125175

Dampers are able to cover stiffness uncertainties, providing solutions to wind-induced vibrations. Sophisticated modelling approaches such as SPH provide efficient simulation of TLDs, such as damping screens. SPH is efficient in simulating nonlinear responses and energy dissipation, and this is supported by experimental evidence as well as facilitating enhanced TLD designs. APEC-PTMD and TLIS with high-damping systems increase vibration control [65-78]. TLIS combines inerter and liquid elements, providing a lightweight, efficient alternative to conventional TLDs. Practical applications, including a full-scale MTSD in a 56-story building, demonstrated a 50% decrease in building accelerations, being economical and feasible. STMDs are useful, but MTMDs are superior, providing higher resilience to dynamic loads like wind and earthquakes, making them a necessity in contemporary engineering. MTLSDs are superior to TLSDs under different structural stiffness conditions [79-83]. By spreading damping across several tanks at different frequencies, MTLSDs damp both base and higher modes, providing improved robustness for high-rise structures. Optimized TLSD configurations, employing nonlinear constraint the innovations are validated with a full-scale Multiple Tuned Sloshing Damper (MTSD) system for a 56-story building with a 50% reduction of acceleration, which is cost-effective. Finally, Single Tuned Mass Dampers (STMDs) work, but Multiple Tuned Mass Dampers (MTMDs) are more efficient at damping dynamic loads such as wind and earthquakes and thus are very important in today's structural engineering [52-64].

## V. CONCLUSION

In general, Multiple Tuned Liquid Sloshing Dampers (MTLSDs) and concurrent advances in damping devices and modelling methods offer highly efficient means to mitigate wind-induced vibrations for high-rise buildings. MTLSDs also possess the additional benefits over conventional Tuned Liquid Sloshing Dampers (TLSDs) by easily responding to structural stiffness changes, with higher serviceability and durability resulting from sophisticated designs. Technologies like Smoothed Particle Hydrodynamics (SPH) simulation and sophisticated systems like APEC-PTMD and TLIS continue to enhance accuracy, effectiveness, and convenience. Implementations on actual building examples, such as successful applications of MTSD systems, demonstrate they are cost-effective and highly effective in mitigating accelerations of structures. All the above technologies combined offer a useful stepping stone in further advancing vibration control in structural engineering.

## REFERENCES

[1]. Suthar, S. J., & Jangid, R. S. (2022). Multiple tuned liquid sloshing dampers for across-wind response control of benchmark tall building. Innov Infrastruct Solut.

[2]. Suthar, S. J., & Jangid, R. S. (2021, October). Design of tuned liquid sloshing dampers using nonlinear constraint optimization for across-wind response control of benchmark tall building. In Structures (Vol. 33, pp. 2675-2688). Elsevier.

[3]. McNamara, K. P., Awad, B. N., Tait, M. J., & Love, J. S. (2021). Incompressible smoothed particle hydrodynamics model of a rectangular tuned liquid damper containing screens. Journal of Fluids and Structures, 103, 103295.

[4]. Wang, L., Nagarajaiah, S., Shi, W., & Zhou, Y. (2020). Study on adaptive-passive eddy current pendulum tuned mass damper for wind-induced vibration control. The Structural Design of Tall and Special Buildings, 29(15), e1793.

[5]. Love, J. S., Morava, B., & Smith, A. W. (2020). Monitoring of a tall building equipped with an efficient multiple-tuned sloshing damper system. Practice Periodical on Structural Design and Construction, 25(3), 05020003.Kaveh, A., & Javadi, S. M. (2019). Chaos-based firefly algorithms for optimization of cyclically large-size braced steel domes with multiple frequency constraints. Computers & Structures, 214, 28-39.

[6]. Zhao, Z., Zhang, R., Jiang, Y., & Pan, C. (2019). A tuned liquid inerter system for vibration control. International Journal of Mechanical Sciences, 164, 105171.

[7]. Elias, S., Matsagar, V., & Datta, T. K. (2019). Dynamic response control of a wind-excited tall building with distributed multiple tuned mass dampers. International Journal of Structural Stability and Dynamics, 19(06), 1950059.

[8]. Solari, G. (2017, November). Wind loading of structures: Framework, phenomena, tools and codification. In Structures (Vol. 12, pp. 265-285). Elsevier.

[9]. Kawai, H. (1992). Vortex induced vibration of tall buildings. Journal of wind engineering and industrial aerodynamics, 41(1-3), 117-128.

[10]. Lamb, S., & Kwok, K. C. (2017). The fundamental human response to wind-induced building motion. Journal of Wind Engineering and Industrial Aerodynamics, 165, 79-85.

[11]. Sun, L. M., Fujino, Y., Pacheco, B. M., & Chaiseri, P. (1992). Modelling of tuned liquid damper (TLD). Journal of Wind Engineering and Industrial Aerodynamics, 43(1-3), 1883-1894.

[12]. Sun, L. M., Fujino, Y., Pacheco, B. M., & Chaiseri, P. (1992). Modelling of tuned liquid damper (TLD). Journal of Wind Engineering and Industrial Aerodynamics, 43(1-3), 1883-1894.

[13]. 13. Love, J. S., & Tait, M. J. (2010). Nonlinear simulation of a tuned liquid damper with damping screens using a modal expansion technique. Journal of Fluids and Structures, 26(7-8), 1058-1077.

[14]. 14. Love, J. S., & Haskett, T. C. (2018). Nonlinear modelling of tuned sloshing dampers with large internal obstructions: Damping and frequency effects. Journal of Fluids and Structures, 79, 1-13.

[15]. 15. Love, J. S., Morava, B., & Smith, A. W. (2020). Monitoring of a tall building equipped with an efficient multiple-tuned sloshing damper system. Practice Periodical on Structural Design and Construction, 25(3), 05020003.

[16]. Nakum, A., Patel, V., & Patel, V. (2015). High Strength Concrete Incorporating Ground Granulated Blast Furnace Slag and Steel Fibres: A Review. International Journal of Structural and Civil Engineering Research. Https://Doi. Org/10.18178/Ijscer, 4, 195–200.

[17]. Nakum, A. B. (2015). Vatsal N patel, vishal B. patel "Experimental study on mechanical and durability properties of high strength concrete incorporating ggbs and steel fibers." International Journal of Engineering Research, 3(4).

[18]. Patel, D., Patel, V., & Arekar, V. (2022). Flexural and Torsional Behavior of Concrete Filled Tubular Flange Girder.

[19]. Gondaliya, S. B., Patel, V. B., & Verma, A. (2016). COMPARATIVE STUDY OF HYPERBOLIC COOLING TOWERS. International Journal of Advance Research in Engineering, Science & Technology, 3(4), 272–281.

[20]. Bhutwala, H. N., Patel, V. B., Rathod, J., & Desai, A. (n.d.). Cyclic Loading Behaviour of Externally Bonded CFRP Reinforced Concrete Beam-Column Joint.Mistry, D. B., Agrawal, V. V., & Patel, V. B. (2021). Comparative Study of Staggered Truss System With and Without Shear Wall. Young, 4(2).

[21]. Patel, D. B., Patel, S. B., & Patel, V. B. (n.d.). A Comparative Study of Flat Slab System and Regular Beam-Slab System for Symmetric and Asymmetric Building Structure.

[22]. Parmar, D., George, E., Patel, V., & Verma, A. (n.d.). FLEXURAL STRENGTH OF FIBER REINFORCED SELF COMPACTING CONCRETE.

[23]. Bhutwala, H. N., Patel, V. B., Rathod, J., & Desai, A. (n.d.). Cyclic Loading Behaviour of Externally Bonded CFRP Reinforced Concrete Beam-Column Joint.

[24]. Shah, S. K., Sinha, Dr. D. A., & George, Dr. E. (2023). Design and durability aspect of hybrid fiber reinforced self-compacting concrete: A Review. IARJSET, 10(4).

[25]. Jani, B., Agrawal, V., & Patel, V. (2020). Effects of soil condition on elevated water tank using time history analysis with different staging systems. International Journal of Civil Engineering, 7, 41–47.Chauhan, G., Patel, V., & Arekar, V. (2017). Applications of harmony search algorithm in structural engineering. 1, 239–247.

[26]. Patel, S. K., Desai, A., & Patel, V. (2011). Effect of number of storeys to natural time period of building. 13–15.

[27]. Rana, U., Mevada, S. V., & Patel, V. B. (2020). Seismic risk assessment of asymmetric frame buildings using fragility curves. Int J Civil Eng, 7(5), 1–9.

[28]. Dabhi, M. G., Agrawal, V. V., & Patel, V. B. (2020). Soil structure interaction for basement system of multi storey building for different soil condition using static analysis in Etabs. SSRG International Journal of Civil Engineering, 7(6).

[29]. Parmar, M. K., Mevada, S. V., & Patel, V. B. (2017, July). Seismic performance evaluation of RCC buildings with different structural configurations. In ICRISET2017. International Conference on Re-search and Innovations in Science, Engineering & Technology (Vol. 1, pp. 375-380).

[30]. Pandit, N. J., Mevada, S. V., & Patel, V. B. (2020). Seismic Vibration Control of a Two-Way Asymmetric Tall Building Installed with Passive Viscous Dampers under Bi-Directional Excitations. SSRG International Journal of Civil Engineering, 7(5), 10–20.

[31]. Zadafiya, N., Patel, V., & Mevada, S. (2019). Vibration Control Using Shared Tuned Mass Damper For SDOF System. International Journal of Emerging Technologies and Innovative Research, 6(4), 283–288.

[32]. Makwana, N. B., Mevada, S. V., & Patel, V. B. (2019). Vibration Control of Asymmetric Building Subjected to Harmonic Excitation. SSRG International Journal of Civil Engineering, 4(5), 75–78.

[33]. Ankola, M., Patel, V., & Mevada, S. (2020). Vibration Control of Adjacent Building using Shared Tuned Mass Damper.

[34]. Mansuri, A. A., Patel, V. B., & Machhi, C. (n.d.). Structural Control Using LRB in Irregular Building.

[35]. Agrawal, A. P., Patel, V. B., & Agrawal, V. V. (n.d.). Static Analysis of Rcc, Partially Encased & Fully Encased Composite Column Supported Elevated Water Tank.

[36]. Bhojani, K., Patel, V., & Mevada, S. (n.d.). Seismic Vibration Control of Building with Lead Rubber Bearing Isolator. 226–219. https://doi.org/10.29007/pvzx

[37]. Rana, U. R., Mevada, S. V., & Patel, V. B. (2022). Seismic Risk Assessment of Asymmetric Buildings using Fragility Curves. 1(6), 1727–1739.

[38]. Kulkarni, M. V. S., Patel, I. N., Agrawal, V. V., & Patel, V. B. (2021). Seismic and Wind Load Analysis of Cable Stayed Bridge. Solid State Technology, 64(2), 7356–7367.

DOI: 10.17148/IARJSET.2025.125175

[39]. Makwana, N., Mevada, S. V., & Patel, V. B. (n.d.). Vibration Control of Building Subjected to Harmonic Excitation.

[40]. Shah, M. I., Patel, V. B., & Mevada, S. V. (n.d.). Comparative Study of Conventional Frame and Diagonally Intersecting Metal with Geometric Irregularities.

[41]. Chauhan, R. F., Mevada, S. V., & Patel, V. B. (n.d.). Vibration Control of Building Using Base Isolation Under Near Fault Earthquakes.

[42]. Bhojani, M. J., Agrawal, V., & Patel, V. (2016). Time History analysis of elevated water tank with different type of bracing system using SAP2000. International Journal of Advance Research in Engineering, Science & Technology, 3(4), 331–336.

[43]. Mistry, A., V. Mevada, S., & V. Agrawal, V. (2022). Vibration Control of Tall Structure using Various Lateral Load Resisting Systems and Dampers. International Journal of Civil Engineering, 9(6), 28–42. https://doi.org/10.14445/23488352/IJCE-V9I6P103

[44]. Patoliya, N., Patel, I. N., & Agrawal, V. V. (2023). Seismic Analysis of Tall Buildings Connected with Sky Bridge. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10446

[45]. . Carpenter, Y. R., Arekar, V. A., & Agrawal, V. V. (2023). Seismic Analysis of Bundled Tall Building Connected with Outrigger System. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10457

[46]. Mehta, A., V. Agrawal, V., & Arekar, V. A. (2023). Codal Comparison of Seismic Analysis for Elevated Water Tank Using Different Codes: A Comprehensive Review. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10464

[47]. Jariwala, D. D., Mevada, S. V., & Arekar, V. A. (2023). Experimental Study on Structure Model with Shear Wall and Base Isolator Under Dynamic Forces. IARJSET, 10(5). https://doi.org/10.17148/IARJSET.2023.10512

[48]. Rana, U., Mevada, S. V., & Patel, V. B. (2020). Seismic risk assessment of asymmetric frame buildings using fragility curves. Int J Civil Eng, 7(5), 1–9.

[49]. Patel, H., Desai, A. N., & Arekar, V. A. (2023). Performance of Confined Masonry in Seismic Zones. IARJSET, 10(5). https://doi.org/10.17148/IARJSET.2023.10520

[50]. Shah, M. I., Mevada, S. V., & Patel, V. B. (2016). Comparative study of diagrid structures with conventional frame structures. Int J Eng Res Appl, 6(5), 22–29.

[51]. Kachchhi, J. M., & Patel, S. V. M. V. B. (n.d.). Comparative Study Of Diagrid Structure With Other Structural Systems For Tall Structures. Global Journal Of Engineering Science And Researches, Issn, 2348–8034.

[52]. Mistry, D. B., Agrawal, V. V., & Patel, V. B. (2021). Comparative Study of Staggered Truss System With and Without Shear Wall. Young, 4(2).

[53]. Patel, K., Patel, V., & Mevada, S. (2020). Design and analysis of core and outrigger structural system. Int. Res. J. Eng. Technol, 7(6).

[54]. Patel, J. P., Patel, V. B., & George, E. (2017). Comparative Study of Triangle Tubes Bundled System and Square Tubes Bundled System. 484–489.

[55]. Shah, A. G., & Patel, V. B. (2020). A Parametric Study of Tall Structures with Diagrid. IUP Journal of Structural Engineering, 13(1), 7–14.

[56]. Kalaria, D. R., Agrawal, V. V., & Patel, V. B. (2019). Parametric study of diagrid structures subjected to seismic forces. J Emerg Technol Innov Res (JETIR), 6(4), 146–153.

[57]. Patel, S. J., & Patel, V. B. (2016). Comparison of different types of tubular systems. International Journal of Advance Research in Engineering, Science & Technology, 3(4), 282–289.

[58]. Upadhyay, M. H., Patel, V. B., & Arekar, V. A. (n.d.). Parametric study on castellated beam with arch-shape openings. SSRG International Journal of Civil Engineering, 8(5), 52–57.

[59]. Mali, A. K., Patel, V. B., & Desai, A. N. (2023). Effect of Dynamic Wind Load on Tall Structure Using Gust Factor Method. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 14(03), 1289–1308. https://doi.org/10.61841/turcomat.v14i03.14299

[60]. Patel, S. J., & Patel, V. B. (2016). Comparison of different types of tubular systems. International Journal of Advance Research in Engineering, Science & Technology, 3(4), 282–289.

[61]. Ranpurwala, K. A., Agrawal, V. V., & Patel, V. B. (n.d.). A Comparative Study on Different Exterior Vertical Grid System in Tall Building.

[62]. Rajdev, D. N., Patel, V. B., & Bhatt, P. M. (2023). A Review of Diagrid and Belt Truss Designs Structural Systems for High-Rise Buildings. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10465

[63]. Nisarg, V., Bhatt, Dr. D., & Mevada, Dr. S. (2023). BRIDGE VIBRATION CONTROL USING VISCOUS DAMPERS. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10462

[64]. Vyas, H., Mevada, S. V., Patel, S. B., & Gupta, A. (2023). Behavior of Connected Tall Buildings Installed with Dampers. IARJSET, 10(5). https://doi.org/10.17148/IARJSET.2023.10513

[65]. Patel, V. B., & Jangid, R. S. (2024). Optimal Parameters for Tuned Mass Dampers and Examination of Equal Modal Frequency and Damping Criteria. Journal of Vibration Engineering & Technologies, 12(5), 7159–7173.

[66]. Patel, V., & Jangid, R. (2022). Closed-form derivation of optimum tuned mass damper parameter based on modal multiplicity criteria. 1(4), 1041–1049.
[67]. Ranpura, N., Areakar, V., & Patel, V. (2021). Optimum design of combined rectangular RCC footing using GA. International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), 7(2), 202–210.
[68]. Chauhan, G., Patel, V., & Arekar, V. (2017). Applications of harmony search algorithm in structural engineering. 1, 239–247.
[69]. Mevada, A., Patel, V., & Arekar, D. (2021). Cost optimization of cantilever retaining wall using flower pollination algorithm. International Journal of Advanced Research in Science, Communication and Technology, 6, 915–930.
[70]. Solanki, D., Arekar, V. A., & Patel, V. B. (2020). Weight Optimization of 3D Steel Trusses using Genetic Algorithm. Population, 7(07).
[71]. Pandit, N., Patel, V., Patel, N., Patel, A., & Pandit, Y. (2024). Prevalence of reproductive tract infection among tribal migrant women living in urban areas: A community-based cross-sectional study. Public Health, 236, 441–444.
[72]. Patel, V. B., & Jangid, R. S. (2024). Optimal Parameters for Tuned Mass Dampers and Examination of Equal Modal Frequency and Damping Criteria. Journal of Vibration Engineering & Technologies, 12(5), 7159–7173.
[73]. Patel, V., & Jangid, R. (2022). Closed-form derivation of optimum tuned mass damper parameter based on modal multiplicity criteria. 1(4), 1041–1049.
[74]. Chauhan, G. R., Patel, V. B., & Arekar, V. A. (2017). Optimization of Beam-Column using Harmony Search Algorithm. International Journal of Advance Research in Engineering, Science & Technology, 4(4), 449–452.
[75]. Desai, A., Ghosh, T., Gupta, M., Nanavaty, N., Patel, V., Rao, B., Taneja, A., Shah, P., Shah, R., & Singh, S. (1997). Post-Marketing Surveillance Study of Typhim Vi. Journal of Association of Physicians of India, 45(3).
[76]. Moteriya, S. A., Patel, V. B., & Arekar, V. A. (2016). Comparative Study of Curved Beam Using Finite Element Analysis (FEA) and Isogeometric Analysis (IGA). International Journal of Advance Research in Engineering, Science & Technology, 3(4), 264–271.
[77]. Shingala, P. J., Arekar, V. A., & Desai, A. N. (2023). Optimization of Industrial Shed Using Fully Stressed Design Method for Butterfly Roof. IARJSET, 10(4). https://doi.org/10.17148/IARJSET.2023.10458
[78]. Patel, V., & Jangid, R. (2022). Closed-form derivation of optimum tuned mass damper parameter based on modal multiplicity criteria. 1(4), 1041–1049.).
[79]. Harish, J. V., Patel, V., & Arekar, V. (2016). Parametric study of various pre-engineered buildings. International Journal of Advance Research in Engineering, Science & Technology, 3(4), 297–302.
[80]. Mamtora, S., Arekar, V., & Patel, V. (n.d.). Optimizing the Weight of Truss using Modified Artificial Bee Colony Algorithm.
[81]. Solanki, D., Arekar, V. A., & Patel, V. B. (2021). Optimization of Trusses Using Genetic Algorithm. Turkish Online Journal of Qualitative Inquiry, 12(7).
[82]. Parmar, M. K., Mevada, S. V., & Patel, V. B. (n.d.). Pushover Analysis of Asymmetric Steel Buildings.
[83]. M. Patel, Y., V. Mevada, S., & V. Agrawal, V. (2022). Vibration Control of Transmission Line Tower using Linear Viscous Dampers. International Journal of Civil Engineering, 9(6), 15–27. https://doi.org/10.14445/23488352/IJCE-V9I6P102
[84]. Love, J. S., McNamara, K. P., Tait, M. J., & Haskett, T. C. (2020). Tuned sloshing dampers with large rectangular core penetrations. Journal of Vibration and Acoustics, 142(6), 061003.
[85]. Kwon, D. K., & Kareem, A. (2020). Hybrid simulation of a tall building with a double-decker tuned sloshing damper system under wind loads. The Structural Design of Tall and Special Buildings, 29(15), e1790.
[86]. Elias, S., & Matsagar, V. (2018). Wind response control of tall buildings with a tuned mass damper. Journal of Building Engineering, 15, 51-60.
[87]. Dai, J., Xu, Z. D., & Gai, P. P. (2019). Tuned mass-damper-inerter control of wind-induced vibration of flexible structures based on inerter location. Engineering Structures, 199, 109585.
[88]. Wang, L., Nagarajaiah, S., Shi, W., & Zhou, Y. (2020). Study on adaptive-passive eddy current pendulum tuned mass damper for wind-induced vibration control. The Structural Design of Tall and Special Buildings, 29(15), e1793.
[89]. Taha, A. E. (2021). Vibration control of a tall benchmark building under wind and earthquake excitation. Practice Periodical on Structural Design and Construction, 26(2), 04021005.
[90]. Suthar, S. J., & Jangid, R. S. (2021, October). Design of tuned liquid sloshing dampers using nonlinear constraint optimization for across-wind response control of benchmark tall building. In Structures (Vol. 33, pp. 2675-2688). Elsevier.
[91]. Liang, Z., Lee, G. C., Dargush, G. F., & Song, J. (2011). Structural damping: applications in seismic response modification. CRC press.
[92]. Kwok, K. C., Burton, M. D., & Abdelrazaq, A. K. (2015, January). Wind-induced motion of tall buildings: designing for habitability. American Society of Civil Engineers.

DOI: 10.17148/IARJSET.2025.125175

[93]. American Society of Civil Engineers. (2017, June). Minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers.
[94]. Kareem, A., & Kijewski, T. (2002). Time-frequency analysis of wind effects on structures. Journal of Wind Engineering and Industrial Aerodynamics, 90(12-15), 1435-1452.
[95]. Banerji, P., Murudi, M., Shah, A. H., & Popplewell, N. (2000). Tuned liquid dampers for controlling earthquake response of structures. Earthquake engineering & structural dynamics, 29(5), 587-602.
[96]. Suhardjo, J., Spencer Jr, B. F., & Kareem, A. (1992). Frequency domain optimal control of wind-excited buildings. Journal of Engineering Mechanics, 118(12), 2463-2481.
[97]. Yang, J. N., & Samali, B. (1983). Control of tall buildings in along-wind motion. Journal of Structural Engineering, 109(1), 50-68.
[98]. Yang, J. N., Wu, J. C., Agrawal, A. K., & Hsu, S. Y. (1997). Sliding mode control with compensator for wind and seismic response control. Earthquake engineering & structural dynamics, 26(11), 1137-1156.
[99]. Yang, J. N. (1998). A benchmark problem for response control of wind-excited tall buildings. In Proc. 2^< nd> world Conference on Structural Control (Vol. 2, pp. 1407-1416). John Wiley & Sons.
[100]. Yang, J. N., Agrawal, A. K., Samali, B., & Wu, J. C. (2004). Benchmark problem for response control of wind-excited tall buildings. Journal of engineering mechanics, 130(4), 437-446.
[101]. Samali, B., Yang, J. N., & Yeh, C. T. (1985). Control of lateral-torsional motion of wind-excited buildings. Journal of engineering mechanics, 111(6), 777-796.