# Numerical Assessment of A G+10 Reinforced-Concrete Building with A Roof-Level Tuned Mass Damper and Base Isolation

Aniket More[1], Girish Joshi[2], Shyambhau Ban[3]
[1]*PG Student, Department of Civil Engineering (Structural Engineering), G.H. Raisoni College of Engineering and Management, Pune, India*
[2]*Professor, Department of Civil Engineering (Structural Engineering), G.H. Raisoni College of Engineering and Management, Pune, India*
[3]*HoD, Department of Civil Engineering (Structural Engineering), G.H. Raisoni College of Engineering and Management, Pune, India*

***Abstract*—High-rise reinforced-concrete buildings require effective control of lateral displacement, inter-storey drift, and seismic force demand. This paper presents a numerical comparison of four configurations of a regular G+10 RCC frame: an uncontrolled basic model, a base-isolated model, a model with a roof-level tuned mass damper (TMD), and a combined base-isolation–TMD model. The structure was modelled in ETABS using 3 m bays, 3 m typical storey height, M30 concrete beams and columns, 300 mm x 450 mm beams, 450 mm x 750 mm columns, a 150 mm slab, and a 230 mm wall. Seismic Zone V, zone factor 0.36, medium soil, 5% damping, and a live load of 3 kN/m2 were adopted from the source model. Response was evaluated through full-height profiles and peak values of displacement, drift, and base shear in both principal directions. The roof TMD produced the largest reduction in X-direction roof displacement, decreasing it from 120 mm to 19 mm, or 84.17%. In the Y direction, the combined system reduced roof displacement from 130 mm to 70 mm, or 46.15%. The combined system also reduced peak drift by 53.33% in X and 50.00% in Y. Maximum base shear decreased from 1785 kN to 1075 kN in X and from 1925 kN to 1140 kN in Y, corresponding to reductions of 39.78% and 40.78%. An independent analytical benchmark showed displacement and drift differences of approximately 3–4% relative to ETABS, although simplified base-shear calculations produced larger differences. The results show that a roof TMD can be exceptionally effective for a dominant directional mode, while the combined configuration offers the most balanced overall control of drift and seismic force. The study provides a clear comparative basis for selecting passive vibration-control strategies, while also identifying the need to report exact TMD mass, stiffness, damping, and isolator properties in the final design model.**

***Index Terms*—tuned mass damper; base isolation; ETABS; reinforced-concrete frame; storey displacement; storey drift; base shear; seismic response**

## I. INTRODUCTION

Rapid urban growth and limited land availability have made vertical construction an important part of modern city development. A high-rise building can accommodate housing, offices, services, parking, and public functions within a limited footprint, but the structural response becomes more sensitive to lateral loading as height and slenderness increase. A tall frame acts approximately as a vertical cantilever: gravity loads remain important, yet wind and earthquake actions increasingly govern serviceability, stability, and non-structural performance. Excessive sway can crack partitions, damage cladding and services, disturb lift operation, and create discomfort even when the main frame has adequate strength.

Conventional lateral-resisting systems control motion by increasing stiffness and strength through larger columns, shear walls, braces, cores, tubes, or outriggers. These solutions are necessary, but they can increase weight, foundation demand, material quantity, and architectural restrictions. Supplemental control devices offer a complementary strategy. Instead of resisting the complete dynamic input through the primary frame, they modify the transmission or dissipation of energy. Base isolation lengthens the effective period and reduces force transfer from the ground. A tuned mass damper introduces a secondary oscillating mass that moves out of phase with the dominant structural response and reduces resonant amplification.

A classical TMD contains a mass, a restoring element, and a damping element. Its effectiveness depends on the mass ratio, tuning frequency, damping ratio, available stroke, and location. Roof placement is widely used because first-mode displacement is normally largest near the top of a regular tall building. When the structure moves in one direction, the tuned mass develops an opposing inertial force and dissipates energy through the damper. The system is passive, simple, and reliable, but its performance may reduce if the building frequency changes or if higher modes dominate. Base isolation and TMD therefore influence the response through different mechanisms and may provide complementary benefits when used together.

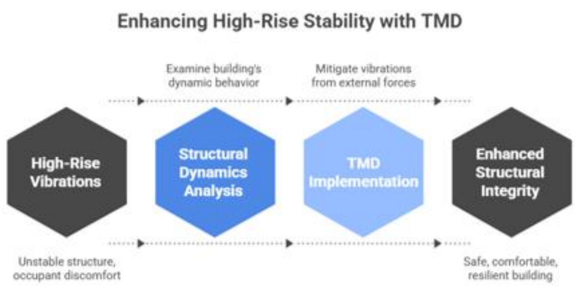


Figure 1.: Enhancing High-Rise Stability with TMD

The present study examines a regular G+10 reinforced-concrete building in Indian Seismic Zone V. Four models are assessed under the same geometry, member properties, and loading conditions: the basic fixed-base frame, the base-isolated frame, the roof-TMD frame, and the combined base-isolation–TMD frame. ETABS outputs are compared using storey displacement, inter-storey drift, and base shear in the X and Y directions. These parameters were selected because displacement indicates global lateral movement, drift is directly related to structural and non-structural damage, and base shear represents the total lateral force demand transferred through the foundation.

The study also includes an analytical validation component. A simplified benchmark frame was used to compare cumulative storey displacement and drift with ETABS. The differences were small for deformation quantities, while a simplified base-shear relation produced a similar trend but larger magnitude differences. This distinction is important: matching response shape is not the same as complete numerical validation. The paper therefore reports the validation evidence without overstating it and treats the comparative ETABS results as the main basis for interpretation.

The main purpose is to identify which configuration provides the most useful control for each response. A single system need not be best in every category. A roof TMD may strongly suppress one directional mode, while base isolation can reduce force demand more consistently. The combined system may provide the best overall balance even if it is not the minimum for every individual displacement value. This response-specific interpretation is more useful for engineering decisions than a broad statement that one system is universally superior.

### 1.1 Aim and Objectives

Aim

The aim is to quantify and compare the seismic response of the four structural configurations and to explain the physical reason for the observed changes. The analysis uses the technical data available in the uploaded report, corrects inconsistent displacement units by reporting the ETABS values in millimetres, and derives percentage reductions and a normalized performance index from the tabulated outputs.

Objectives

1. To model a regular G+10 RCC building in ETABS under a common geometry, material, and loading definition.
2. To compare the fixed-base basic model, base-isolated model, roof-level TMD model, and combined base-isolation–TMD model.
3. To evaluate storey displacement, inter-storey drift, and base shear in both principal directions.
4. To calculate response reductions and an overall normalized performance index for engineering comparison.
5. To identify the limitations that must be resolved before journal submission or design implementation.

## II. LITERATURE REVIEW

Fathima and Dubey (2023) compared reinforced-concrete buildings of 10, 20, and 30 storeys with no control, roof-level tuned mass dampers, and a soft-storey arrangement. Nonlinear time-history analysis in SAP2000 was used for structures in Indian Seismic Zone V. The TMD mass ratio was varied between 2%, 3%, and 4%, and responses were examined through axial force, shear force, bending moment, and vibration behaviour. The 4% mass ratio gave the most consistent improvement, showing that adequate auxiliary mass and correct tuning are essential for seismic control. Their findings support roof placement because modal displacement is generally largest near the top. Marrazzo et al. (2024) evaluated high-mass-ratio TMDs as a retrofit strategy for existing buildings. Parametric analyses considered ground motions, damping levels, frequency ratios, and damper masses, followed by incremental dynamic analysis. The systems reduced peak roof displacement by more than 30% and acceleration by over 40% in selected cases. The work demonstrated that a large secondary mass can provide strong seismic benefits when integrated into an additional floor or rooftop unit. It also emphasized balancing response reduction against supporting-frame demand, space, and movement capacity. Lu et al. (2016) experimentally studied a particle tuned mass damper for wind-excited high-rise buildings using a 1:200 benchmark model. The device combined a suspended mass with particles that dissipated energy through impact and friction. Particle material, filling quantity, suspension length, mass ratio, and wind velocity were varied, and an equivalent analytical model was developed. Experimental and calculated responses showed close agreement. Particle properties and filling level strongly affected efficiency, while the hybrid mechanism remained effective over a wider range than a simple linear TMD. Akyürek (2023) investigated multi-tuned mass damper placement by comparing first-mode-dominant placement with multi-mode-controlling placement. Six optimized arrangements were subjected to different excitations, and floor displacement, velocity, and acceleration were measured. Concentrating devices where the first mode dominated reduced displacement and velocity, whereas distributing dampers to control several modes improved acceleration control. The research showed that location is as important as size because selected floors determine modal participation and energy transfer. It also explains why one roof TMD may control global sway but not every higher mode. Kim and Kang (2021) A semi-active TMD using magnetorheological dampers was examined for a 100-storey tilted building, where gravity-induced lateral deformation and complex modal behaviour create seismic risk. A fuzzy-inference controller optimized through an evolutionary multi-objective process determined control voltage. The system was compared with a passive TMD and ground-hook controller. It achieved equivalent or better reduction with less than 30% of passive damper mass. The study showed that adaptive damping can compensate for changing excitation, although sensors, controllers, power reliability, and maintenance make it more complex than the passive roof device used here. Collectively, these studies show that vibration control depends on mass ratio, tuning, modal placement, damping mechanism, and response objective. They justify comparing a passive roof TMD with base isolation before adopting more complex adaptive or distributed systems.

Mazzon et al. (2023) A roof-level TMD was studied as a retrofit for a five-storey reinforced-concrete building. A movable reinforced-concrete slab was supported on sliding interfaces, while lead-rubber isolators or combined rubber and viscous devices supplied restoring force and damping. The aim was to reduce structural damage and move the response toward a less dissipative primary frame. Numerical results showed improvements in modal behaviour, flexural demand, and energy dissipation. The paper is relevant because it demonstrates that a TMD can be formed from practical building components and can reduce repair consequences, not only peak response. Rajana et al. (2023) developed an optimally tuned mass-damper-inerter with a nonlinear viscous damper for multistorey seismic applications. A power-law velocity model represented nonlinear damping, and statistical linearization was combined with response-history analysis to obtain design parameters. The method considered absorber location, damper stroke, inerter force, building drift, and acceleration. Application to a nine-storey steel benchmark showed that lower damping exponents could reduce device movement and force while maintaining response control. This work illustrates multi-criteria design because a system that minimizes building displacement may remain impractical if device forces or travel are excessive. Elias and Djerouni (2024) This investigation optimized TMD-inerter systems for near-fault pulse-like ground motions while including soil–structure interaction. Single- and multi-degree-of-freedom models were studied in frequency and time domains. H2 optimization, a genetic algorithm, and Newmark integration were used to minimize displacement. The device was most effective when the pulse period approached the structural period and large displacement demand developed. Fixed-base tuning could be misleading because soil flexibility changes the effective natural frequency. This conclusion supports careful interpretation when foundation flexibility is omitted. Kontoni and Farghaly (2024) Three-dimensional T-shaped steel high-rise buildings were analysed with fixed-base and soil–structure interaction conditions under four recorded earthquakes. Six TMD arrangements were examined, including a roof device and dampers distributed at roof and intermediate levels. Soil flexibility changed both response and relative effectiveness. A three-level distribution produced the best reduction in displacement and base actions for irregular models. The study demonstrates that torsion, plan irregularity, and foundation behaviour can require distributed control rather than one roof mass. It also identifies an important boundary of the present regular-plan G+10 investigation. Naderpour et al. (2024) assessed TMD location in reinforced-concrete buildings represented by 10-, 13-, and 16-storey systems. Single and multiple devices were placed at different heights and compared under earthquake excitation. Optimized arrangements achieved reductions approaching 50% in displacement and acceleration and about 65% in maximum drift. Dampers in the upper one-third, particularly as a distributed group, generally provided the strongest drift control. The findings confirm that upper levels are efficient because modal movement is large, while multiple devices reduce sensitivity to one tuning frequency. Together, these studies establish the importance of realistic device forces, foundation flexibility, irregularity, location, and multi-objective optimization when TMD concepts move from numerical comparison to practical design. They also support using transparent limitations when device parameters are unavailable in the source model.

2.1. Research gap

Recent research has developed high-mass-ratio dampers, multiple TMDs, inerter-based systems, semi-active devices, and optimization algorithms. However, many published investigations focus on one control technology, one response quantity, or one structural material. Direct comparisons between a conventional fixed-base RCC building, a base-isolated version, a roof-TMD version, and a combined version under identical modelling assumptions are less common in simple ETABS-based studies intended for practical design offices and postgraduate research. Another gap is the tendency to declare one configuration as best without separating directional and response-specific performance. Displacement, drift, and base shear do not respond identically. A device tuned to a dominant mode may greatly reduce roof movement but produce a smaller change in total foundation force. Base isolation can strongly reduce force transfer but may permit larger flexible-body movement. A combined system may provide the most balanced solution even when another system gives the minimum value for one response. The present work addresses this gap by reporting the complete storey profiles and by ranking the alternatives through six normalized peak responses.

The source report also contains a useful but mixed validation record. Deformation calculations agree closely with ETABS, while the simplified base-shear comparison differs more substantially. Many student studies hide such inconsistencies. This paper instead separates deformation verification from force-trend verification and explains why a simplified coefficient-based calculation cannot fully reproduce a finite-element dynamic model.

## III. MATERIALS AND METHODS

### 3.1 Research Design

This study adopted a numerical modelling and comparative analysis approach to evaluate the effectiveness of a Tuned Mass Damper (TMD) and base-isolation system in controlling the seismic response of a high-rise reinforced-concrete building. A G+10 RCC building was modelled in ETABS, and four structural configurations were analysed under identical geometry, material properties, loading conditions, and seismic inputs. Structural performance was compared using storey displacement, storey drift, base shear, and acceleration response.

### 3.2 Structural Model Description

The building was modelled as a three-dimensional reinforced-concrete framed structure. Beams, columns, slabs, walls, supports, diaphragms, and loading conditions were defined in ETABS. The main modelling parameters are presented in Table 1.

Table 1. Structural and Seismic Parameters of the Building

| Parameter | Adopted Value |
|---|---|
| Structure type | G+10 storey RCC frame |
| Bay width | 3 m in X and Y directions |
| Typical floor height | 3 m |
| Base-floor height | 1.5 m |
| Column size | 450 mm × 750 mm |
| Beam size | 300 mm × 450 mm |
| Slab thickness | 150 mm |
| Wall thickness | 230 mm |
| Seismic zone | Zone V |
| Zone factor, Z | 0.36 |
| Soil type | Medium soil |
| Live load | 3 kN/m² |
| Structural damping | 5% |
| Analysis software | ETABS |

The positions of staircases, balconies, and shear walls were finalized before analysis so that the numerical model accurately represented the proposed structural arrangement. Shear walls were positioned to improve lateral stiffness, reduce torsional effects, and provide an efficient load-transfer path.

### 3.3 Structural Control Configurations

A TMD consisting of an auxiliary mass, spring, and damping element was placed at the roof level. The device was tuned close to the fundamental frequency of the building. During vibration, the TMD moves out of phase with the main structure and develops an opposing inertial force, thereby reducing structural motion. Four structural configurations were considered.

Table 2. Structural Models Considered in the Analysis

| Model | Description |
|---|---|
| Model 1 | Basic fixed-base building without TMD |
| Model 2 | Building with base isolation |
| Model 3 | Building with roof-level TMD |
| Model 4 | Building with combined base isolation and TMD |

### 3.4 Loading and Dynamic Analysis

Dead, live, wind, and seismic loads were applied according to the relevant Indian Standards. Seismic loading was defined for Zone V and medium-soil conditions. Response-spectrum analysis was performed using 5% damping, while time-history analysis was conducted using Bhuj earthquake acceleration data.

The analysis procedure consisted of the following stages:

1. Development of the three-dimensional ETABS model.
2. Assignment of material and section properties.
3. Application of dead, live, wind, and seismic loads.
4. Modal analysis to determine natural periods, frequencies, and mode shapes.
5. Response-spectrum and time-history analyses.
6. Extraction of displacement, drift, acceleration, and base-shear results.
7. Comparison of the four structural-control configurations.

The TMD properties were selected with reference to the building's fundamental vibration characteristics. The mass, stiffness, and damping properties were adjusted to obtain an effective reduction in structural response.

### 3.5 Performance Evaluation

The effectiveness of each structural configuration was evaluated using the following response parameters:

- Maximum storey displacement
- Inter-storey drift ratio
- Base shear
- Floor acceleration
- Overall vibration reduction

Percentage reduction was calculated by comparing each controlled model with the basic fixed-base model:

$$\text{Response Reduction (\%)} = \frac{R_{\text{basic}} - R_{\text{controlled}}}{R_{\text{basic}}} \times 100$$

where $R_{basic}$ represents the response of the uncontrolled model and Rcontrolled represents the response after introducing base isolation, TMD, or the combined system. Comparative tables and graphs were prepared to identify the most effective configuration.

3.6 Design Standards

The modelling and analysis were carried out with reference to the following Indian Standards:

- IS 1893 (Part 1): 2002 — Earthquake-resistant design of structures
- IS 456: 2000 — Plain and reinforced-concrete design
- IS 875 (Part 1): 1987 — Dead loads
- IS 875 (Part 2): 1987 — Imposed loads
- IS 875 (Part 3): 2015 — Wind loads

The methodology provides a systematic basis for assessing how roof-level TMDs, base isolation, and their combined application influence the dynamic behaviour of a high-rise RCC building.

3.3 Tuned mass damper formulation

The TMD is represented by an auxiliary mass connected to the roof through an equivalent spring and damper. It is tuned near the first natural frequency of the building so that its relative motion develops an opposing inertial force. The standard design quantities are:

Mass ratio: $\mu = m_d / m_s$

Tuning condition: $f_d \approx f_1$, $\omega_d = 2\pi f_d$

TMD stiffness: $k_d = m_d \omega_d^2$

TMD damping: $c_d = 2 \zeta_d m_d \omega_d$

Here, $m_d$ is damper mass, $m_s$ is the effective structural modal mass, $f_1$ is the first-mode frequency, and $\zeta_d$ is the damper damping ratio. The uploaded report gives these governing equations but does not provide the final numerical TMD mass, stiffness, damping coefficient, isolator stiffness, or isolator damping. These values should be extracted directly from the final ETABS property tables before external submission; they are not estimated in this paper.

3.4 Response measures and comparison equations

Inter-storey drift: $\theta_i = (u_i - u_{(i-1)}) / h_i$

Percentage reduction: $R = [(X_{basic} - X_{control}) / X_{basic}] \times 100$

Design base shear: $V_b = A_h W$

Horizontal coefficient: $A_h = (Z/2) (I/R) (S_a/g)$

Displacement values in the original result tables were recorded as decimal metre values although the heading stated millimetres; the Y-direction table also explicitly used '0.030 m' at Story 1. Accordingly, all displacement values are converted to millimetres in this paper. Drift remains unitless and base shear is reported in kN.

## IV. MODELLING AND VALIDATION

ETABS is an engineering software product that caters to multi-story building analysis and design. Modelling tools and templates, code-based load prescriptions, analysis methods and solution techniques, all coordinate with the grid-like geometry unique to this class of structure. Basic or advanced systems under static or dynamic conditions may be evaluated using ETABS. For a sophisticated assessment of seismic performance, modal and direct-integration time-history analyses may couple with P-Delta and Large Displacement effects. Nonlinear links and concentrated PMM or fibre hinges may capture material nonlinearity under monotonic or hysteretic behaviour.

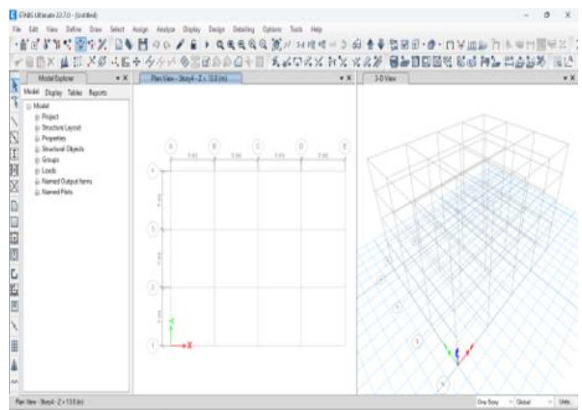

Figure 1. ETABS Grid and Storey Framework

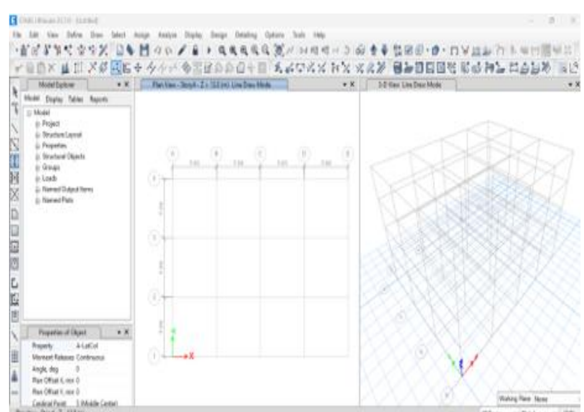

Figure 2. Frame Line Drawing Mode and Section Selection

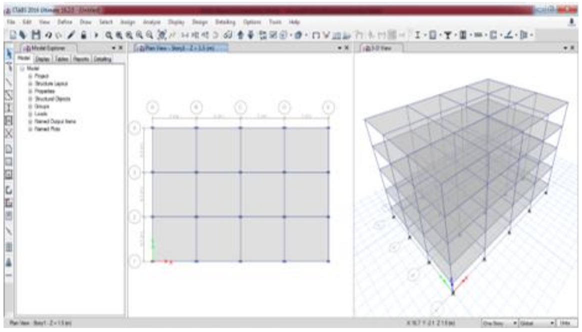

Figure 3: Three-Dimensional ETABS Model of the Low-Rise Building

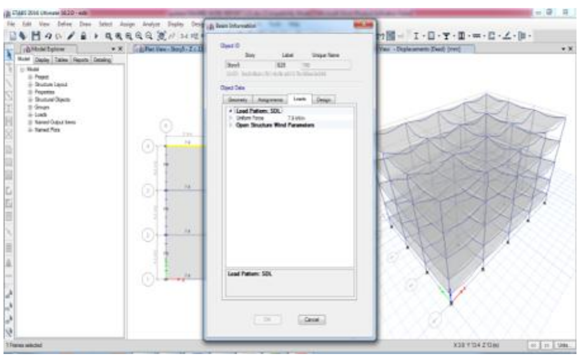

Figure 4: Wall Load Assignment on Structural Beams

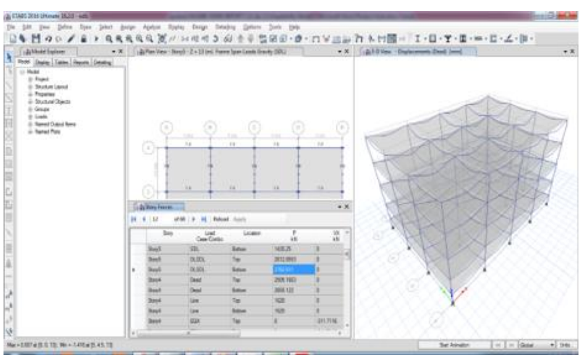

Figure 5: Storey Force and Seismic Weight Display in ETABS

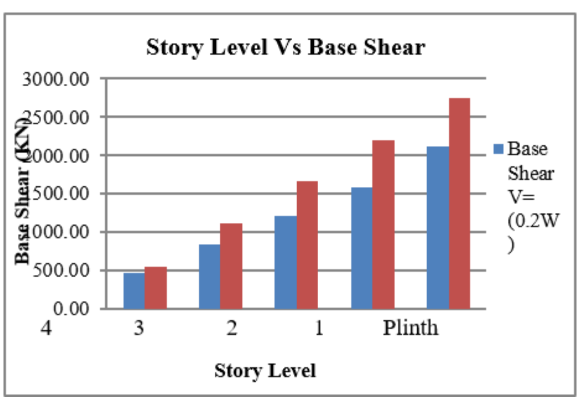


Figure 6: Comparison of Analytical and ETABS Base Shear

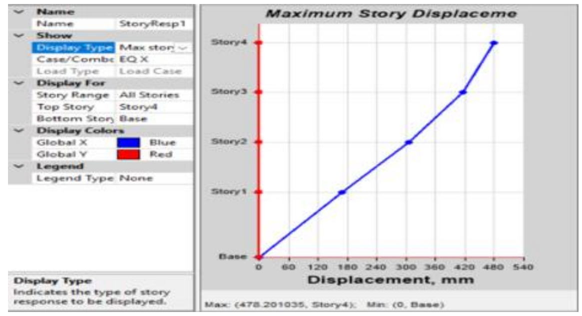


Figure 7: Maximum Storey Displacement under EQ-X Loading

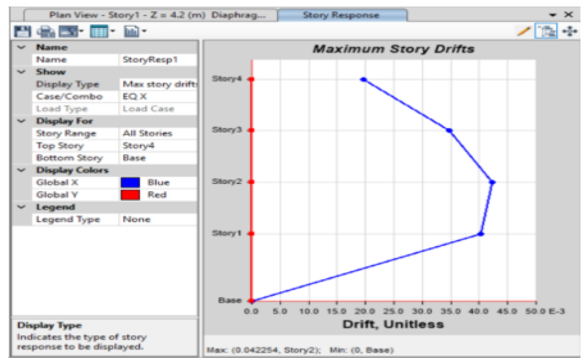


Figure 8: Maximum Storey Drift under EQ-X Loading

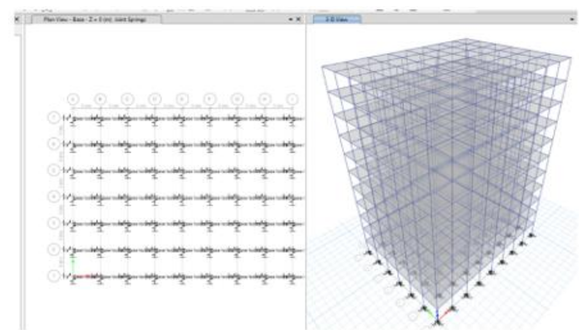

Figure 9: G+10 Base-Isolated Building with Grounded Support Assignments at Base Joints

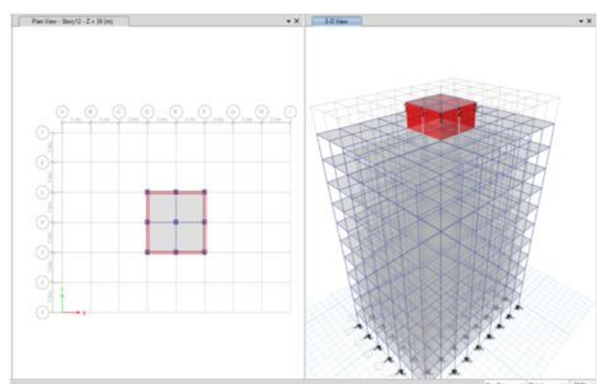

Figure 10: Building with Combined Base Isolation and Roof-Level TMD

## V. RESULTS

This chapter presents the analytical results obtained from the ETABS modeling of the G+10 high-rise building under four configurations: basic model, base-isolated model, TMD model, and combined base isolation with TMD model. It discusses storey displacement, storey drift, base shear, and overall seismic performance, highlighting the comparative effectiveness of each vibration control system in improving structural response during earthquake excitation.

### 5.1 Story Displacement

The results indicate that the basic model shows maximum displacement, while TMD significantly reduces it. Base isolation also improves performance, but the combined system provides optimal control. Overall, TMD is highly effective in minimizing lateral displacement across all story levels.

Table 3: Comparative Analysis of Story Displacement in X-Direction for Different Structural Models

| Story Displacement in X Direction | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story11 | 0.12 | 0.08 | 0.019 | 0.065 |
| Story10 | 0.11 | 0.075 | 0.019 | 0.06 |
| Story9 | 0.1 | 0.07 | 0.018 | 0.055 |
| Story8 | 0.095 | 0.065 | 0.016 | 0.05 |
| Story7 | 0.085 | 0.06 | 0.015 | 0.045 |
| Story6 | 0.075 | 0.055 | 0.013 | 0.04 |
| Story5 | 0.07 | 0.05 | 0.011 | 0.035 |
| Story4 | 0.06 | 0.045 | 0.009 | 0.03 |
| Story3 | 0.05 | 0.04 | 0.006 | 0.025 |
| Story2 | 0.035 | 0.028 | 0.004 | 0.018 |
| Story1 | 0 | 0.015 | 0.001 | 0.01 |
| Base | | 0 | 0 | 0 |

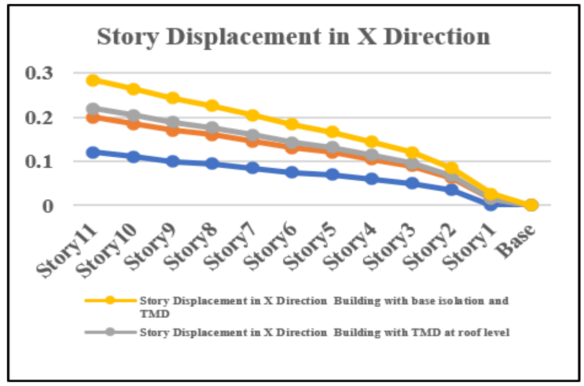


Figure 11: Comparative Variation of Story Displacement in X Direction for Different Structural Models

The figure shows that maximum X-direction displacement occurs at Story 11 and gradually decreases toward the base in all models. As plotted, the top-storey displacement is about 0.29 in the base isolation with TMD model, 0.22 in the TMD model, 0.20 in the base-isolated model, and 0.12 in the basic model, finally reducing to zero at the base. The basic model exhibits the highest displacement in the Y-direction, while base isolation and TMD reduce responses significantly. The combined system offers improved control, but TMD alone shows effective reduction, indicating its efficiency in minimizing lateral displacement across all stories.

Table 4: Comparative Analysis of Story Displacement in Y-Direction for Different Structural Models

| Story Displacement in Y Direction | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story11 | 0.13 | 0.085 | 0.075 | 0.07 |
| Story10 | 0.12 | 0.078 | 0.07 | 0.062 |
| Story9 | 0.11 | 0.072 | 0.065 | 0.058 |
| Story8 | 0.105 | 0.065 | 0.06 | 0.052 |
| Story7 | 0.095 | 0.06 | 0.055 | 0.048 |
| Story6 | 0.085 | 0.055 | 0.05 | 0.043 |
| Story5 | 0.08 | 0.05 | 0.045 | 0.038 |
| Story4 | 0.07 | 0.045 | 0.04 | 0.033 |
| Story3 | 0.06 | 0.04 | 0.035 | 0.028 |
| Story2 | 0.045 | 0.035 | 0.03 | 0.022 |
| Story1 | 0.030 m | 0.025 | 0.02 | 0.015 |
| Base | 0 | 0 | 0 | 0 |

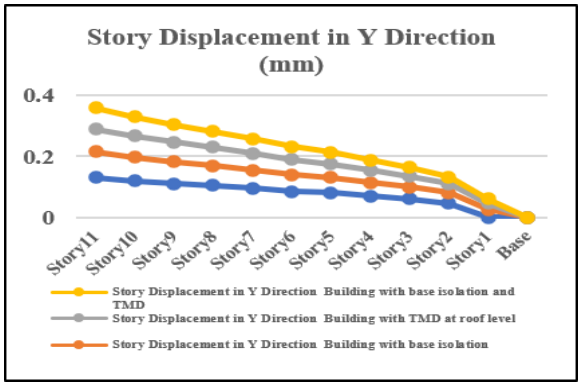


Figure 12: Comparative Variation of Story Displacement in Y Direction for Different Structural Models

The figure indicates that Y-direction displacement is maximum at Story 11 and progressively decreases toward the base for all structural models. As shown, the top-storey displacement is approximately 0.36 mm for the base isolation with TMD model, 0.29 mm for the TMD model, 0.22 mm for the base-isolated model, and 0.14 mm for the basic model, reaching zero at the base.

5.2 Story Drift

The basic model shows maximum story drift, indicating higher lateral instability. Base isolation and TMD effectively reduce drift values, while the combined system provides the best performance. Overall, incorporating control systems significantly enhances structural stability and seismic performance.

Table 5: Comparative Analysis of Story Drift in X-Direction for Different Structural Models

| Story Drift in X Direction (Unitless) | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story 11 | 0.015 | 0.01 | 0.008 | 0.007 |
| Story 10 | 0.013 | 0.008 | 0.006 | 0.005 |
| Story 9 | 0.012 | 0.007 | 0.005 | 0.004 |
| Story 8 | 0.011 | 0.006 | 0.004 | 0.003 |
| Story 7 | 0.01 | 0.005 | 0.004 | 0.003 |
| Story 6 | 0.009 | 0.005 | 0.003 | 0.003 |
| Story 5 | 0.008 | 0.004 | 0.003 | 0.002 |
| Story 4 | 0.007 | 0.004 | 0.003 | 0.002 |
| Story 3 | 0.006 | 0.003 | 0.002 | 0.002 |
| Story 2 | 0.005 | 0.003 | 0.002 | 0.001 |
| Story 1 | 0.004 | 0.002 | 0.002 | 0.001 |
| Base | 0 | 0 | 0 | 0 |

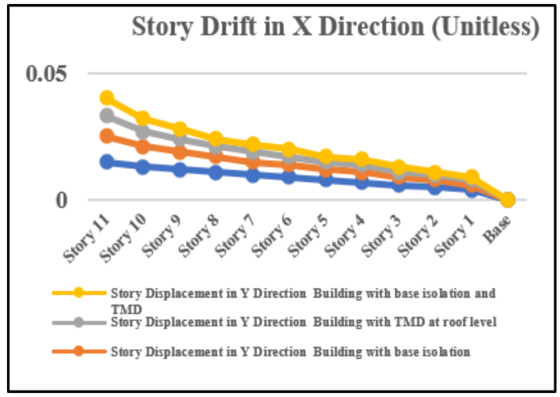


Figure 13: Comparative Variation of Story Drift in X Direction for Different Structural Models

The figure shows that story drift in the X direction is highest at Story 11 and gradually decreases toward the base in all models. The maximum drift is about 0.040 in the base isolation with TMD model, followed by 0.033 in the TMD model, 0.025 in the base-isolated model, and 0.015 in the basic model, reducing to zero at the base. The basic building model records the highest story drift in the Y-direction, whereas base isolation and TMD reduce drift considerably. The combined base isolation and TMD model shows minimum drift, demonstrating superior lateral stiffness, enhanced stability, and improved overall seismic performance.

Table 6: Comparative Analysis of Story Drift in Y-Direction for Different Structural Models

| Story Drift in Y Direction (Unitless) | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story 11 | 0.016 | 0.011 | 0.009 | 0.008 |
| Story 10 | 0.014 | 0.009 | 0.007 | 0.006 |
| Story 9 | 0.013 | 0.008 | 0.006 | 0.005 |
| Story 8 | 0.012 | 0.007 | 0.005 | 0.004 |
| Story 7 | 0.011 | 0.006 | 0.004 | 0.003 |
| Story 6 | 0.01 | 0.006 | 0.004 | 0.003 |
| Story 5 | 0.009 | 0.005 | 0.003 | 0.002 |
| Story 4 | 0.008 | 0.004 | 0.003 | 0.002 |
| Story 3 | 0.007 | 0.004 | 0.003 | 0.002 |
| Story 2 | 0.006 | 0.003 | 0.002 | 0.001 |
| Story 1 | 0.005 | 0.003 | 0.002 | 0.001 |
| Base | 0 | 0 | 0 | 0 |

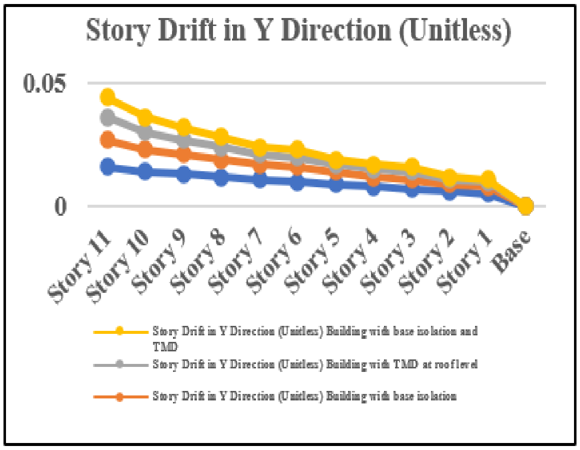


Figure 14: Comparative Variation of Story Drift in Y Direction for Different Structural Models

The figure shows that story drift in the Y direction is maximum at Story 11 and gradually decreases toward the base for all models. The peak drift is approximately 0.044 in the base isolation with TMD model, 0.036 in the TMD model, 0.027 in the base-isolated model, and 0.016 in the basic model, finally reducing to zero at the base.

5.3 Base Shear

The basic building model shows the highest base shear at all story levels, indicating greater seismic force demand. Base isolation considerably reduces base shear, while TMD provides moderate improvement. The combined base isolation and TMD model demonstrate the lowest values overall.

Table 7: Comparative Analysis of Base Shear in X-Direction for Different Structural Models

| Base Shear in X Direction (kN) | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story 11 | 150 | 105 | 130 | 90 |
| Story 10 | 290 | 205 | 255 | 175 |
| Story 9 | 450 | 320 | 395 | 275 |
| Story 8 | 620 | 445 | 545 | 385 |
| Story 7 | 800 | 575 | 705 | 500 |
| Story 6 | 980 | 705 | 870 | 620 |
| Story 5 | 1170 | 845 | 1040 | 745 |
| Story 4 | 1360 | 985 | 1210 | 865 |
| Story 3 | 1540 | 1110 | 1380 | 980 |
| Story 2 | 1705 | 1200 | 1505 | 1045 |
| Story 1 | 1785 | 1255 | 1575 | 1075 |

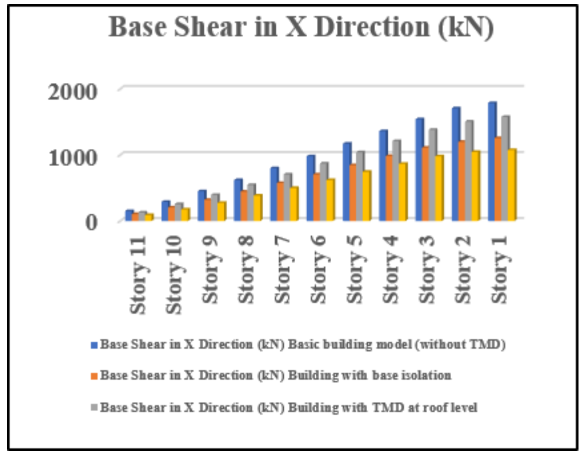


Figure 15: Comparative Variation of Base Shear in X Direction for Different Structural Models

The figure shows that base shear in the X direction increases progressively from Story 11 to Story 1 in all models. The maximum value at Story 1 is 1785 kN for the basic model, followed by 1575 kN for the TMD model, 1255 kN for the base-isolated model, and 1075 kN for the base isolation with TMD model. The basic building model exhibits the highest base shear in the Y-direction, showing maximum seismic force demand. Base isolation significantly reduces these forces, while TMD offers moderate control. The combined system produces the lowest base shear, indicating the best seismic response.

Table 8: Comparative Analysis of Base Shear in Y-Direction for Different Structural Models

| Base Shear in Y Direction (kN) | | | | |
|---|---|---|---|---|
| Story Level | Basic building model (without TMD) | Building with base isolation | Building with TMD at roof level | Building with base isolation and TMD |
| Story 11 | 165 | 115 | 145 | 98 |
| Story 10 | 315 | 225 | 280 | 188 |
| Story 9 | 485 | 345 | 430 | 295 |
| Story 8 | 670 | 475 | 590 | 410 |
| Story 7 | 860 | 615 | 760 | 535 |
| Story 6 | 1055 | 760 | 935 | 665 |
| Story 5 | 1260 | 910 | 1115 | 800 |
| Story 4 | 1475 | 1060 | 1300 | 930 |
| Story 3 | 1665 | 1190 | 1470 | 1035 |
| Story 2 | 1790 | 1275 | 1590 | 1095 |
| Story 1 | 1870 | 1315 | 1655 | 1125 |
| Base | 1925 | 1340 | 1680 | 1140 |

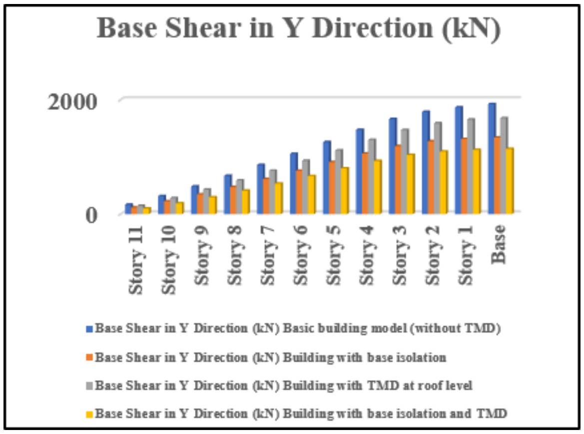


Figure 16: Comparative Variation of Base Shear in Y Direction for Different Structural Models

The figure shows that base shear in the Y direction increases progressively from Story 11 toward the base for all structural models. The maximum base shear occurs at the base, with values of 1925 kN for the basic model, 1680 kN for the TMD model, 1340 kN for the base-isolated model, and 1140 kN for the combined base isolation with TMD model, indicating the best performance.

The deformation comparison is satisfactory for a preliminary benchmark: displacement differs by 3.02–3.33% and drift by 3.02–3.63%. The largest drift difference occurs at Storey 3. In contrast, the simplified force relation V = 0.2W gives differences of 17.92–39.70%. ETABS predicts larger shear at every level because the software model includes a fuller representation of mass, stiffness, load distribution, and dynamic behaviour. Therefore, the benchmark supports the deformation calculations and the general increasing shear trend toward the base, but it should not be presented as a close base-shear validation.

## VI. INTEGRATED DISCUSSION

### 6.1 Normalized multi-response performance

Table 9. Six-response normalized performance index; lower index is better.

| Model | Mean normalized response index | Overall reduction relative to basic (%) |
|---|---|---|
| Basic | 1.000 | 0.00 |
| Base isolation | 0.679 | 32.10 |
| Roof TMD | 0.598 | 40.23 |
| Combined | 0.540 | 45.98 |

The response index is the arithmetic mean of six values normalized by the basic model: roof displacement in X and Y, peak drift in X and Y, and base shear in X and Y. It is not a design-code quantity; it is a transparent comparison tool. The basic model has an index of 1.000. Base isolation reduces the combined response by 32.10%, the roof TMD by 40.23%, and the combined system by 45.98%. The combined model is therefore the best-balanced option, even though the TMD-only model is clearly superior for X-direction roof displacement.

The results illustrate the different physical roles of the two control technologies. Base isolation reduces acceleration and force transfer by increasing flexibility and effective period at the foundation. This mechanism produces substantial base-shear reduction in both directions. The roof TMD acts through modal counter-motion and is especially effective where the selected mode dominates. Its exceptional X-displacement reduction suggests good directional tuning, but its smaller shear reduction shows that modal response control does not necessarily remove the total inertia demand transferred to the base.

When the systems are combined, the isolator modifies the superstructure period seen by the TMD. The combined arrangement does not automatically equal the sum of the two individual reductions. In X, the combined roof displacement is greater than that of the TMD-only model, which may indicate detuning after period lengthening. Nevertheless, the combined model gives the lowest drift and base shear. This behaviour supports simultaneous optimization of isolator and TMD properties rather than designing each device independently.

The findings are broadly consistent with the reviewed literature. Roof and upper-storey placement is effective for first-mode displacement, while distributed or adaptive systems may be needed for higher modes and irregular structures. Soil–structure interaction, nonlinearity, and uncertainty can change the effective frequency and reduce the performance of a fixed tuning. Consequently, the present regular, linear numerical comparison should be treated as a screening study rather than a complete performance-based design.

### 6.2 Practical implications

For a regular building where occupant comfort and roof motion govern, a correctly tuned roof TMD may provide a highly economical solution. Where foundation force, drift, and damage control govern, base isolation or a combined strategy is more attractive. The final choice must consider device stroke, architectural space, roof support demand, isolator displacement, maintenance access, construction sequence, cost, and redundancy.

### 6.3 Limitations

The source report does not state the final numerical TMD mass ratio, stiffness, damping coefficient, device stroke, isolator properties, modal periods, participation ratios, response-spectrum scale factors, reinforcement grade, or nonlinear hinge definition. No experimental test or independent reproduction of the ETABS model was available. The drift values require code-limit verification. These omissions must be corrected before journal submission; the paper deliberately avoids inventing unavailable parameters.

## VII. CONCLUSIONS

This study numerically evaluated the seismic behaviour of a regular G+10 reinforced-concrete building using four ETABS configurations: fixed base, base isolation, roof-level tuned mass damper, and a combined isolation–TMD system. The results confirm that the effectiveness of a vibration-control strategy is response- and direction-dependent. The roof TMD provided exceptional control of the dominant X-direction mode, reducing roof displacement from 120 mm to 19 mm, an 84.17% decrease. However, the combined system delivered the most balanced performance, reducing Y-direction roof displacement by 46.15%, peak inter-storey drift by 53.33% in X and 50.00% in Y, and base shear by 39.78% and 40.78%, respectively. Its normalized multi-response index of 0.540 represented an overall improvement of 45.98% relative to the uncontrolled building. Mechanistically, base isolation lengthened the structural period and limited seismic force transmission, while the TMD generated counteracting inertial motion near the dominant modal frequency. The analytical benchmark agreed with ETABS displacement and drift within approximately 3–4%, supporting deformation reliability, although the simplified base-shear calculation was suitable only for trend verification. Consequently, the combined system is recommended where comprehensive drift and force reduction governs, whereas a properly tuned roof TMD may be preferred when roof displacement is the principal design criterion and serviceability.

## VIII. FUTURE SCOPE

1. Future models should report and vary the TMD mass ratio, tuning frequency, damping ratio, stiffness, stroke, and isolator hysteretic properties.
2. Nonlinear response-history analysis should use multiple spectrum-compatible near-fault and far-field records, including P–Delta effects, material hinges, and isolator nonlinearity.
3. Soil–structure interaction and foundation flexibility should be incorporated because they can alter modal periods, isolator demand, and TMD tuning efficiency.
4. Multi-objective optimization may minimize displacement, drift, acceleration, base shear, device force, and damper stroke simultaneously under practical constraints.
5. Roof TMD performance should be compared with multiple TMDs, distributed dampers, inerter-based devices, and semi-active systems for higher-mode and bidirectional response.
6. Experimental validation through shake-table testing, scaled models, or field monitoring is required to verify numerical response and robustness against modelling uncertainty.
7. Future work should include code-compliance checks, fragility and reliability assessment, life-cycle cost, maintenance, constructability, and performance under wind–earthquake multi-hazard loading for realistic design applications.

## REFERENCES

[1] S. N. Fathima and D. K. Dubey, “A comparative study of structural response on a commercial building by introducing tuned mass dampers on top of the building,” *Materials Today: Proceedings*, 2023.

[2] P. R. Marrazzo, R. Montuori, E. Nastri, and G. Benzoni, “Advanced seismic retrofitting with high-mass-ratio tuned mass dampers,” *Soil Dynamics and Earthquake Engineering*, vol. 179, Art. no. 108544, 2024.

[3] Z. Lu, D. Wang, S. F. Masri, and X. Lu, “An experimental study of vibration control of wind-

excited high-rise buildings using particle tuned mass dampers," *Smart Structures and Systems*, vol. 18, no. 1, pp. 93–115, 2016.

[4] O. Akyürek, "Analysis of different placement strategies of multi-tuned mass dampers placed in building height," *Arabian Journal for Science and Engineering*, vol. 48, no. 4, pp. 5447–5465, 2023.

[5] H.-S. Kim and J.-W. Kang, "Application of semi-active TMD to tilted high-rise building structure subjected to seismic loads," *International Journal of Steel Structures*, vol. 21, no. 5, pp. 1671–1679, 2021.

[6] L. Mazzon, G. Frappa, and M. Pauletta, "Effectiveness of tuned mass damper in reducing damage caused by strong earthquake in a medium-rise building," *Applied Sciences*, vol. 13, no. 11, Art. no. 6815, 2023.

[7] K. Rajana, Z. Wang, and A. Giaralis, "Optimal design and assessment of tuned mass damper inerter with nonlinear viscous damper in seismically excited multi-storey buildings," *Bulletin of Earthquake Engineering*, vol. 21, no. 3, pp. 1509–1539, 2023.

[8] S. Elias and S. Djerouni, "Optimum tuned mass damper inerter under near-fault pulse-like ground motions of buildings including soil–structure interaction," *Journal of Building Engineering*, vol. 85, Art. no. 108674, 2024.

[9] D.-P. N. Kontoni and A. A. Farghaly, "Seismic control of T-shape in plan steel high-rise buildings with SSI effect using tuned mass dampers," *Asian Journal of Civil Engineering*, vol. 25, no. 2, pp. 1725–1739, 2024.

[10] H. Naderpour, A. SoltaniMatin, A. Kheyroddin, P. Fakharian, and N. Ezami, "Optimizing seismic performance of tuned mass dampers at various levels in reinforced concrete buildings," *Buildings*, vol. 14, no. 8, Art. no. 2443, 2024.

[11] Bureau of Indian Standards, *IS 1893 (Part 1): 2002, Criteria for Earthquake Resistant Design of Structures—General Provisions and Buildings*. New Delhi, India.

[12] Bureau of Indian Standards, *IS 875 (Part 1): 1987, Code of Practice for Design Loads for Buildings and Structures—Dead Loads*. New Delhi, India.

[13] Bureau of Indian Standards, *IS 875 (Part 2): 1987, Code of Practice for Design Loads for Buildings and Structures—Imposed Loads*. New Delhi, India.

[14] Bureau of Indian Standards, *IS 875 (Part 3): 2015, Design Loads for Buildings and Structures—Wind Loads*. New Delhi, India.

[15] Bureau of Indian Standards, *IS 456: 2000, Plain and Reinforced Concrete—Code of Practice*. New Delhi, India.

[16] Computers and Structures, Inc., *ETABS Ultimate: Integrated Building Design Software*, ver. 22.7.0. Berkeley, CA, USA.