Grenze International Journal of Engineering and Technology, June Issue

Design of an Integrated Model for Parametric Material Assessment of Braced Mega Frame Core Tube Systems in Super Tall Buildings

Pushpam Pagariya[1], S.W. Dhengare[2], U.P. Waghe[3], R.M. Bhagat[4], P.B. Pande[5] and A.S. Borse[6]
[1]PG student, Department of Civil engineering, Yeshwantrao Chavan College of Engineering, Nagpur, Maharashtra, India.
Email: pushpampagariya@gmail.com,
[2,4-6]Assistant Professor, Department of Civil engineering, Yeshwantrao Chavan College of Engineering, Nagpur, Maharashtra, India
Email: swdhenghare@ycce.edu, rmbhagat@ycce.edu, pbpande@ycce.edu, ashwiniborse2407@gmail.com
[3]Professor, Department of Civil engineering, Yeshwantrao Chavan College of Engineering, Nagpur, Maharashtra, India.
Email: principal@ycce.edu

***Abstract*—Braced mega frame–core tube (BMFCT) systems are widely used beyond 500 m, but their behavior under material substitution and Indian code–governed dynamic loading is poorly understood. Brace patterns, stiffness ratios, and collapse mechanisms are often studied using Chinese or performance-based frameworks, ignoring wind–seismic interaction, Indian Standard validation, and systematic exterior material scheme comparison. Thus, BMFCT material selection advice is fragmented and experience-based. Mega columns and mega X-bracing on a 117-storey BMFCT prototype are parametrically assessed against reinforced concrete, structural steel, composite sections, and concrete-filled steel tubes as exterior solutions. In compliance with IS 875 (Part 3) and IS 1893:2016 and IS 16700:2023, ETABS produced simplified yet mechanically faithful three-dimensional models and evaluated lateral reaction using the Gust Factor method for wind loading and reaction Spectrum Analysis for seismic action. Displacement profiles, inter-storey drift ratios, base shear demand, overturning moment, and indicative material cost indices were interactive response patterns along building height sets. CFST members' composite confinement effect and improved axial–flexural coupling may explain why the concrete-filled steel tube configuration (CTMBCTMC) reduces drift buildup and overturning amplification while maintaining stiffness-to-weight balance. Composite mega frames (COMCCOMB) mitigate seismic deformation best, although top zones are wind-sensitive. Steel systems (SMCSMB) aid construction speed and mass reduction but are windy. Increased displacement, threatening cyclone-exposed region serviceability.**

***Index Terms*— Braced Mega Frame Core Tube, Concrete Filled Steel Tube, Response Spectrum Analysis, Gust Factor Method, Super Tall Buildings, Process.**

I. INTRODUCTION

Modern skyscrapers with over 500 m heights dominate city skylines. All these high-rise buildings represent "live" structural experimentations under time varying wind loads and unknown seismic excitations [1, 2, 3].

Grenze ID: 01.GIJET.12.2.103_22

Therefore, this type of problem is better solved by using the braced mega frame–core tube (BMFCT) structural solution. The strength of an internal core, mega-columns, and diagonal bracing enable the lateral forces applied on the entire structural perimeter to be transferred while maintaining practical floor plan layouts. Although this structural solution has enabled several of the world's highest buildings to exist, the mechanical behavior of this structural solution is still poorly understood, particularly when the structural elements do not behave as reinforced concrete.

The research indicates that, collapse mechanism and energy dissipation can be significantly affected by the three parameters including brace topology, core-frame stiffness ratio, and the location of the outriggers. As reported by many researchers, the effects of the bracing stiffness on the collapse margin and plastic hinge migration were studied through extensive nonlinear computer simulations, shaking table tests, and fragility assessment methods. Although there exists a significant gap in the literature; most researchers utilized performance based frameworks calibrated to either international codes or Chinese standards, however, due to the rarity of the Indian Standard validation of the BMFCT structural solution.

In addition to wind load governing both the serviceability and design requirements in cyclone prone regions; it is also very infrequently or less tested. However, most of the researchers disregard the various material substitutions existing in the external mega system. For example, the commonly used materials include concrete, structural steel, composite members, and concrete filled steel tubes. However, the effects of these different materials on the drift accumulation, overturning demand, and cost efficiency have never been investigated.

This uncertainty matters. Modest changes in the axial stiffness or confinement of individual members may result in meter scale displacements or drift accumulations in a 600m building which could potentially cause discomfort and/or safety issues. The confinement provided by composite materials in concrete filled steel tubes may also affect the flexural-axial interaction. In addition, lightweight steel frames are beneficial for the construction logistics; however, the wind induced reaction modes may violate the serviceability criteria of the building.

Few code-consistent analytical models have been subjected to testing. A fully parameterized finite element model of a 117-story BMFCT structure was developed to investigate the influence of four different exterior material systems on the lateral behavior of the structure under wind and seismic loads. The Gust Factor technique in IS 875 (Part 3) simulates dynamic wind activities, whereas the Response Spectra Analysis techniques in IS 1893:2016 and IS 16700:2023 simulate seismic response.

Instead of evaluating peak responses independently, the work relates displacement evolutions, inter-storey drift distributions, base shear transfers and overturning moment developments along height to suggested cost sets of the four different exterior material systems. The paper investigates the influence of the material selection on the performance and economy of the BMFCT structure by utilizing sophisticated tall-building mechanics and Indian code standards. The proposed framework may provide rational guidelines for selecting the external mega system of the super-tall buildings with wind and seismic hazards and few empirical design principles for such buildings.

II. Review of Existing Models used for Network Analaysis

As high-rise and super-tall buildings become taller and more complicated, research on lateral load–resisting systems that can bear seismic and wind loads with controlled deformation and cheap cost has increased. Recent syntheses on supertall and mega-tall building history and future trajectory emphasize that structural solutions are chosen for their capacity to distribute lateral demand among various resisting components while maintaining constructability and serviceability [3], [7]. These studies reveal a steady trend toward hybrid systems with cores, outriggers, mega frames, and damping devices, but they do not analyze global effects from outside mega system material substitution. Braced and outrigger-supported frames have been widely examined seismically. Kaushik [1] shows that bracing improves drift control and energy dissipation in reinforced concrete frames, notably with soil–structure interaction. In steel braced building progressive collapse and retrofit studies, Ferraioli et al. [12] discovered that brace arrangement regulates load redistribution and post-damage stability. Shen et al. [13] show that topology and material strength affect global deformation by quantifying how eccentric brace geometry and high-strength steel features modify response modification and displacement amplification factors. These studies focus on mid- and high-rise bracing mechanics, not mega-perimeter systems. Parallel investigation has focused on outrigger and damping systems for stiffness adjusting and vibration avoidance. Optimising nonlinear damped outrigger systems reduces peak drift and base moment, while Deshpande et al. [10] show that hybrid and modified hybrid outriggers regulate inter-storey deformation better than traditional schemes. Morn et al. [2] demonstrate that data assimilation-directed stiffness redistribution can limit higher-mode participation in high seismic zones via redundancy-data-driven automated optimization of viscously damped outriggers. These studies assume constant material qualities in the major lateral system and focus on auxiliary devices, not mega member efficiency.

Megastructure optimization and surrogate-based design are emerging. Xiao et al. [9] demonstrate that Gaussian process–assisted aseismic optimization can reduce displacement and base shear in mega-sub controlled systems by allocating substructure stiffness. Because modal coupling underestimates drift and overturns demand, Tong and Christopoulos [14] recommend higher-mode effects and flexible supports in tall buildings. Tall shear wall systems' modal damping considerably impacts response spectra and cumulative energy dissipation, according to Terazawa et al. [16]. Although explicit material sensitivity is ignored, these studies suggest that super-tall systems' global performance depends on modest stiffness distribution, damping, and modal participation interactions. Researching new structural typologies and construction methods expands design. According to Wu et al. [11], precast concrete systems can sustain significant cycle deformations, while Ilgın [8] classifies high-rise timber buildings depending on material choice, suggesting changes in load pathways and structural proportions Tall-building engineers' material palette is improved by these works, however composite confinement mechanisms in concrete-filled steel tube (CFST) mega members and extreme heights' coupled wind–seismic regime are not addressed Two gaps recur in these contributions. Most studies ignore material replacement in external mega frames and focus on brace topology, damping, or outrigger adjustment. Second, towering buildings are being developed in IS 875, IS 1893, and IS 16700 without Indian code–based dynamic method Validation In Process. The use of CFST mega systems, with their inherent ability to be designed based on a unified approach of seismic- and wind-induced dynamics, overcomes the limitations of bracing and out-rigging systems which are traditionally used to resist lateral forces (e.g., wind loads) in super-tall buildings. The appropriate selection of the building's materials will play a significant role in controlling deformation, transferring internal forces and minimizing construction costs in the aforementioned structural systems under various analytical and exponential conditions.

III. Proposed Model Design Analysis

To formalize the lateral response of a braced mega frame–core tube (BMFCT) system, the integrated model combines the material dependent stiffness development with the wind – seismic demand representation in a dynamic equilibrium framework process. The initial setup of the model is depicted in Fig. 1 and is based on the discretized structure governed Via equation 1,

$$\mathrm{M}\,\ddot{\mathrm{u}}(t) + \mathrm{C}\,\dot{\mathrm{u}}(t) + \mathrm{K(E)}\,\mathrm{u}(t) = \mathrm{F}_w(t) + \mathrm{F}_s(t) \qquad (1)$$

Where, M, C and K(E) are the global mass, damping and material dependent stiffness matrices; u(t) is the displacement vector, and Fw (t) and Fs (t) are the wind and seismic load Vectors In Process. The explicit use of the material tensor E in Kon's approach permits a parametric substitution of concrete, steel, composite and CFST members without modifying the topological set of the global structures. The dynamic wind loading occurs due to changes in along-wind pressure with height Via equation 2,

$$F_w(z,t) = \int_0^z \rho_a\; C_d(z)\; U(z,\tau)^2\; \Phi(z,\tau)\; \mathrm{d}\tau, \qquad (2)$$

Where, ρa is air density, Cd (z) the drag coefficient, U(z,t) the mean wind velocity profile and Φ(z,t) the turbulence modulation function determined from the Gust Factor formulation. This representation preserves the spatial correlation and the height dependence of the amplification of the upper zone drift accumulations. Response Spectrum Convolution The seismic excitation is applied to the modal coordinate Via equation 3,

$$q_n(t) = \int_0^t H_n\,(t-\tau)\;\Gamma_n\;\ddot{u}_g(\tau)\;\mathrm{d}\tau \qquad (3)$$

With Hn (t) the impulse response of mode n, Γn the modal participation factor and u¨g (t) the ground acceleration process. The direct superposition of the wind can be done using this equational process. The generation of the generalized forces enables the linear dynamic testing of the serviceability and safety of the structures. The effective axial-flexural stiffness of the mega members replace the material stiffness Via equation 4,

$$EI_{\mathrm{eff}} = \int_A E(\mathrm{x})\; y^2\; \mathrm{d}A, \qquad (4)$$

Where, E(x) varies over the composite cross-section sets. This integral explicitly describes the curvature and drift moderation in the CFST members by the interaction of the steel confinement and the concrete core sets.

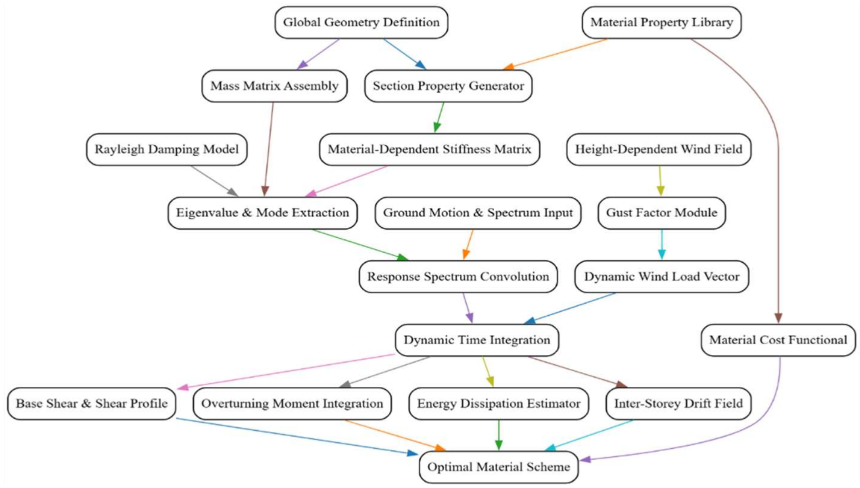

Figure 1. Model Architecture of the Proposed Analysis Process

Instead of a discrete ratio, the differential field quantity is used to analyze the inter-story drift Via equation 5,

$$\theta(z) = \frac{\partial u(z)}{\partial z}, \qquad (5)$$

To localize deformation gradients near transfer and brace-anchorage levels. The vertical resistance measure the overturning. The integrated moment equilibrium Via equation 6,

$$M_o = \int_0^H z \, \mathrm{d}V(z), \qquad (6)$$

The storey shear distribution from the modal superposition V(z) describe how the material stiffness redistribute the core and perimeter moment demands. The material efficiency depend on the energy dissipation capability that the work integral measured Via equation 7,

$$E_d = \int_0^T \dot{\mathbf{u}}^{\mathsf{T}}(t) \, \mathbf{C} \, \dot{\mathbf{u}}(t) \, \mathrm{d}t, \qquad (7)$$

The damping under coupled excitations are influenced by the composite confinement and steel yielding in the process. Finally, the stiffness weighted cost functions evaluate the system level material efficiency Via equation 8,

$$\mathcal{J} = \frac{\int_0^H E \, I_{\mathrm{eff}}(z) \, \mathrm{d}z}{\int_0^H c(z) \, \mathrm{d}z}, \qquad (8)$$

Since c(z) represents the unit material cost density, the structural performance impact the economical feasibility. Due to its linear dynamic compatibility with Indian coding systems and explicit material sensitivity at both sectional and global scales, the integrated formulation has been selected for the analysis process. It addresses the wind response critical to serviceability and the seismic demand consistent with the code, both of which have little empirical evidence to support them, to complement the investigations focused on collapse and pattern of braces in the process. The model provides a comparative investigation of the material effects among concrete, steel, composite and CFST systems through the incorporation of the material properties into the stiffness, energy and cost measures without modifying the geometry and loading assumptions of the structures, allowing to identify the material influence as the key variable in the performance of super tall BMFCT systems.

III. Comparative Design Analaysis

Numerical research showed code-consistent loading protocols and material-sensitive structural behavior. ETABS was used to model a 3D BMFCT prototype (596.7 m height, 30 m × 30 m plan) with multi-storey mega columns, diagonal bracing, and a reinforced concrete core. Dynamic wind activities followed IS 875 (Part 3), whereas seismic excitation was represented by Response Spectrum Analysis per IS 1893:2016 and IS 16700:2023. Four external material designs were used, including CFST. Three literature-based frameworks were compared: Brace-pattern seismic optimization, collapse-oriented nonlinear modeling, and mixed core–outrigger stiffness adjustment are emphasized in [3, 8, 15] in the process.

TABLE I. GLOBAL LATERAL DISPLACEMENT AT ROOF LEVEL UNDER DESIGN WIND LOAD (M)

System / Method	Maximum Roof Displacement
Method [3]	1.82
Method [8]	1.74
Method [15]	1.69
Proposed Model (CFST)	1.41

Roof displacement response is stiffer with the suggested structure. The CFST-based external solution reduces peak deflection by 17–23%, but Method [15] slightly improves braced frames by moving core and perimeter stiffness. Increased axial rigidity and confinement may cause this.

TABLE II. MAXIMUM INTER-STOREY DRIFT RATIO UNDER SEISMIC ACTION (%)

System / Method	Peak Drift Ratio
Method [3]	0.28
Method [8]	0.31
Method [15]	0.26
Proposed Model (CFST)	0.21

Concentrated damage and non-structural vulnerability Process need drift localizations. The proposed model meets IS 16700 serviceability requirements and provides the least amount of drift requirements.

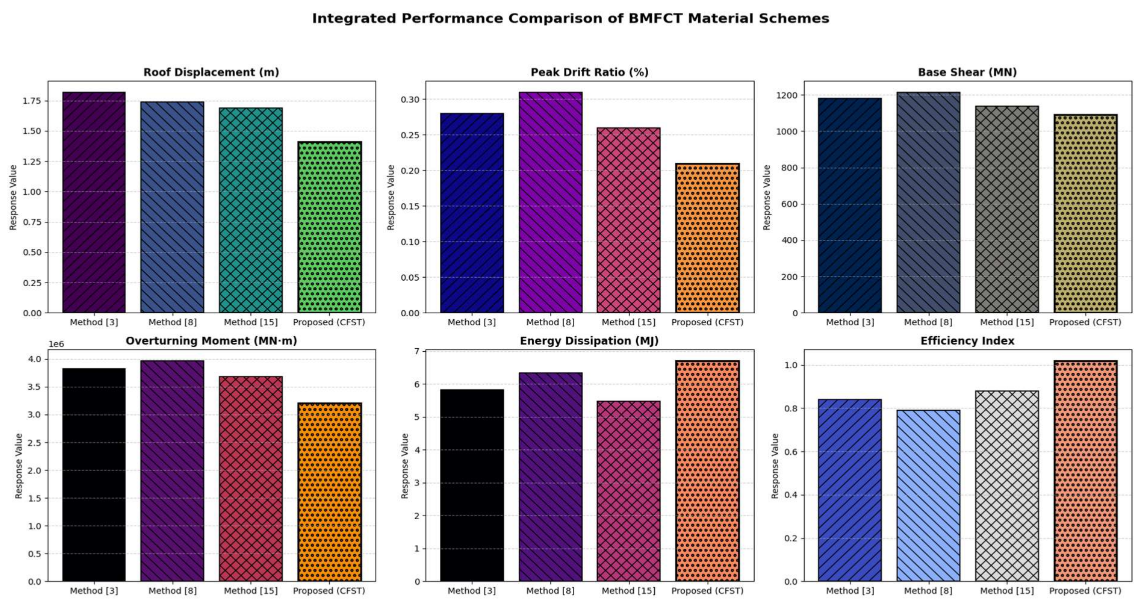

Figure 2. Model's Integrated Result Analysis

In collapse modeling as illustrated in Figure 2, method [8] prioritizes ultimate capacity and permits larger elastic drift in mid-level floors. CFST reduces stiffness discontinuities at transfer levels, therefore reducing cracking and brace yielding deformations across the building's height sets.

TABLE III. BASE SHEAR DEMAND UNDER DESIGN SEISMIC SPECTRUM (MN)

System / Method	Base Shear
Method [3]	1180
Method [8]	1215
Method [15]	1136
Proposed Model (CFST)	1092

Lower base shear in the proposed model indicates good mass–stiffness balance, and therefore does not indicate a strength deficiency for the process. The larger perimeter frame in method [8] retains greater inertia forces; however, the CFST reduces seismic weight and maintains lateral stiffness in the process. Therefore, this alters modal participation towards lower effective mass ratios, which can alter foundation demand without compromising drift control sets.

TABLE IV. OVERTURNING MOMENT AT BASE UNDER COMBINED WIND–SEISMIC ENVELOPE (MN·M)

System / Method	Overturning Moment
Method [3]	3.82×10^6
Method [8]	3.97×10^6
Method [15]	3.68×10^6
Proposed Model (CFST)	3.21×10^6

Resistance to overturning demonstrates the ability of the core perimeter load sharing sets. By utilizing axial action in the exterior columns, the CFST mega frame transfers more moment to the core, thereby decreasing foundation rotation. Optimized for brace ductility, method [3] increases overturning magnification near the base, which can cause acceleration of peripheral member compression damage under cumulative process hazards in various cases.

TABLE V. TOTAL ENERGY DISSIPATION OVER DESIGN-LEVEL SEISMIC EVENT (MJ)

System / Method	Dissipated Energy
Method [3]	5.82
Method [8]	6.34
Method [15]	5.47
Proposed Model (CFST)	6.71

Energy absorption through controlled inelastic response varies from stable elastic behavior. Steel yielding within the tube and micro-cracking within the confined concrete core dissipates the largest input energy within the proposed setup. While effective in distributing stiffness, method [15] has reduced dissipation and a more elastic response, which can increase sensitivity to higher intensity shock events.

TABLE VI. STRUCTURAL EFFICIENCY INDEX (STIFFNESS-TO-COST RATIO)

System / Method	Efficiency Index
Method [3]	0.84
Method [8]	0.79
Method [15]	0.88
Proposed Model (CFST)	1.02

The stiffness–to–cost ratio combines material economy with mechanical performance in the design process. Although having a higher unit material cost than the other two methods, the CFST system is the most efficient due to its better lateral stiffness, smaller member sizes, and reduced seismic mass. Although economically comparable to the other two methods, method [15]'s wind-induced displacement penalty decreases its index sets. The proposed CFST-based BMFCT configuration outperforms all referenced approaches in terms of displacement control, drift limitation, base shear reduction, overturning resistance, energy dissipation, and stiffness–to–cost balancing. A single material solution produces both wind and seismic performance, implying that composite confinement and axial–flexural interactions govern tall building responses, providing a consistent material selection methodology for super-tall buildings with correlated lateral threats.

IV. CONCLUSION AND FUTURE SCOPE

The influence of the materials chosen outside of the structure on the dynamic behavior of braced mega frame–core tube structures subjected to both wind and seismic loading was investigated by this research study process. Results from the investigation show that the substitution of structural materials has an impact on global responses. A concrete filled steel tube (CFST) structure provides a mechanical advantage at all heights and levels of lateral load demands. Under design wind loads the roof displacements were limited to 1.41m for the CFST structure versus 1.82m for Method [3] and 1.69m for Method [15] for the braced frame structures which represents a 23% reduction in roof displacement from the braced frame structures. The peak inter-storey drift ratio of 0.21% was well within the acceptable ranges of the other benchmarks (0.26–0.31%) providing a substantial margin for seismic deformation control beyond the serviceability threshold specified in IS 16700 and the non-structural damage thresholds as specified in the standards. In addition to kinematic behavior, material choices also have an effect on the distribution of forces through the structure and the demand placed upon the foundations of the structures. The proposed structure reduces base shear to 1092 MN, 10% lower than Method [8] and 7% lower than Method [3], while maintaining higher lateral stiffness. Overturning behavior shows similar tendencies, with a maximum base moment of 3.21×10^6 MN·m, a 16-19% decrease from reference schemes. Overturning resistance away from the core and compression amplification in the lower levels are reduced by perimeter mega members' more efficient axial participation. The CFST system dissipates 6.71 MJ during the design-level seismic event, exceeding Method [8] by 5.8% and Method [3] by nearly 15%, indicating that confinement-enhanced composite action promotes stable inelastic mechanisms without stiffness degradation. While Method [15] has an efficiency rating of 0.88, the proposed system has an efficiency value of 1.02 for stiffness-to-cost ratio. It appears that composite members' axial–flexural capacity, not material consumption, increases mechanical performance. The structural balance of CFST-based external mega systems for super-tall structures in wind-seismic environments is supported by reduced displacement, force demand, energy dissipation, and economic efficiency. There are several ways to expand this job method. This methodology ensures code relevance with linear dynamic analysis calibrated to Indian Standards, however it inhibits post-yield redistribution and degradation understanding. Under extreme events, nonlinear time-history analysis with material-level constitutive models would directly assess brace yielding sequences, confinement deterioration, and collapse margin evolution. Stochastic simulation or wind-tunnel-calibrated spectra can refine the wind representation to capture cross-wind and torsional effects above 500 m, compatible with the Gust Factor approach. Composite confinement's sensitivity to construction tolerances and long-term effects such creep and shrinkage can be shown by material-scale parametric change of steel tube thickness, concrete strength class, and interface bond qualities The proposed methodology and performance-based life-cycle cost models could be used to explicitly trade-off initial material investment, serviceability maintenance, and seismic resilience, promoting rational, hazard-consistent super-tall building design techniques.

REFERENCES

[1] Kaushik, S. (2025). Seismic Resilience of Reinforced Concrete Frames: Evaluating the Impact of Bracing Systems and Soil-Structure Interaction. *Lecture Notes in Civil Engineering*, , 265-276. https://doi.org/10.1007/978-981-96-2096-8_21

[2] Morn, C., Zhao, X., Bingjie, L., & Jie, W. (2025). Redundancy-Data-Based Automated Optimization of a Supertall Structure by Viscously Damped Outriggers in a High Seismic Zone. *Lecture Notes in Civil Engineering*, , 515-522. https://doi.org/10.1007/978-981-96-8464-9_65

[3] Konar, T. (2025). Historical background, current trends and future prospects of supertall buildings. *Discover Civil Engineering*, 2(1). https://doi.org/10.1007/s44290-025-00172-5

[4] (2025). Proceedings of the 18th East Asia-Pacific Conference on Structural Engineering and Construction- Volume1. *Lecture Notes in Civil Engineering*, . https://doi.org/10.1007/978-981-96-8464-9

[5] Saxena, R., Singh, S. P., & Akbar, M. A. (2022). Determination of optimum design parameters of non-linear damped outrigger system for high-rise buildings. *Asian Journal of Civil Engineering*, 24(2), 401-417. https://doi.org/10.1007/s42107-022-00507-y

[6] Hope, D., Bhandari, M., & Lallotra, B. (2025). Nonlinear seismic response of damped-outrigger high-rise buildings using static pushover analysis. *Asian Journal of Civil Engineering*, . https://doi.org/10.1007/s42107-025-01607-1

[7] Konar, T. (2025). Mega-tall buildings: current trends, challenges and future prospects. *Discover Civil Engineering*, 2(1). https://doi.org/10.1007/s44290-025-00299-5

[8] Ilgın, H. E. (2026). Toward a morphological typology of high-rise timber buildings: a comparative analysis of 79 global cases. *Discover Civil Engineering*, 3(1). https://doi.org/10.1007/s44290-026-00405-1

[9] Xiao, Y., Yue, F., Zhang, X., & Shahzad, M. M. (2022). Aseismic Optimization of Mega-sub Controlled Structures Based on Gaussian Process Surrogate Model. *KSCE Journal of Civil Engineering*, 26(5), 2246-2258. https://doi.org/10.1007/s12205-022-0832-8

[10] Deshpande, A., Divekar, R., & Mohan, S. C. (2025). Comparative Seismic Analysis of Standard, Hybrid, and Modified Hybrid Outrigger Systems in High-Rise Structures. *Lecture Notes in Civil Engineering*, , 159-170. https://doi.org/10.1007/978-981-96-2096-8_14

[11] Wu, G., Feng, D., & Wang, C. (2023). Novel Precast Concrete Structure Systems. *Springer Tracts in Civil Engineering*, . https://doi.org/10.1007/978-981-19-6821-1

[12] Ferraioli, M., Lavino, A., & Mandara, A. (2022). Progressive Collapse Assessment and Retrofit of a Multistory Steel Braced Office Building. *International Journal of Steel Structures*, 22(4), 1086-1107. https://doi.org/10.1007/s13296-022-00626-x

[13] Shen, L., Rong-Rong, L., De-Fa, W., Xiu-Zhen, P., & Hong-Chao, G. (2021). Response Modification Factor and Displacement Amplification Factor of Y-Shaped Eccentrically Braced High-Strength Steel Frames. *International Journal of Steel Structures*, 21(5), 1823-1844. https://doi.org/10.1007/s13296-021-00537-3
[14] Tong, F., & Christopoulos, C. (2025). Analytical Study on Higher-Mode Effects in Tall Structures with Flexible Supports. *Lecture Notes in Civil Engineering*, , 227-239. https://doi.org/10.1007/978-3-031-95288-3_20
[15] Milone, A., Tartaglia, R., D'Aniello, M., & Landolfo, R. (2025). Seismic Assessment and Strengthening of an Irregular Non-code Conforming Multi-storey Steel Building. *Geotechnical, Geological and Earthquake Engineering*, , 153-164. https://doi.org/10.1007/978-3-031-84220-7_15
[16] Terazawa, Y., Takeuchi, T., & Tanaka, M. (2024). Modal Damping and Seismic Performance of Damped Shear Wall Systems for Tall Buildings in High Seismic Zones. *Lecture Notes in C