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Seismic Performance Evaluation of Conventional and Offset Outrigger with Belt Truss Systems in Tall Buildings

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Abstract Tall buildings are highly vulnerable to lateral loads such as wind and earthquakes due to their slender geometry and height. To enhance their seismic performance, structural systems like outriggers and belt dresses are widely adopted. Traditionally, outriggers are connected directly to the central core, but recent advancements have explored the use of offset outriggers, which are placed away from the core, offering design flexibility and improving internal space utilization. This study investigates and compares the seismic performance of three structural configurations: A Base model without outriggers, a model with conventional outriggers and a model with offset outriggers combined with belt trusses. The analysis was performed using STAAD.Pro, considering seismic loads as per IS 1893:2019. Key performance indicators such as lateral displacement, story drift, base shear, and overturning moment were evaluated to assess the effectiveness of each configuration. Results show that both outrigger systems significantly improved seismic performance compared to the baseline, with the offset outrigger and belt system achieving the greatest reduction in lateral displacement (up to 35%) and better drift control.

Keywords Offset Outrigger, Belt Truss, Tall Buildings, Seismic Performance, Lateral Displacement, Storey Drift

1. Introduction

Buildings that are tall and extremely tall are now necessary for vertical city expansion due to growing urbanization and land scarcity. Significant lateral stresses from seismic and wind activity directly affect the safety and serviceability of these structures. While seismic loads contribute dynamic and irregular stresses that, if left unchecked, can result in substantial base shear and overturning moments, wind loads generate lateral displacement and sway.

There are several lateral load-resisting solutions available to address these issues, and for tall buildings, the outrigger and belt truss system has shown to be a successful option. Outriggers significantly increase lateral stiffness and decrease overturning moments and inter-story drifts by connecting the central core to outside columns via rigid horizontal elements (Fig. 1). This boosts overall stability without causing the core size to expand excessively.

Conventional, offset, virtual, multi-level, and belt truss-integrated outrigger layouts are in use. By connecting outriggers to a belt truss and efficiently dispersing forces across several columns, the offset outrigger with belt truss provides architectural flexibility and increased rigidity.

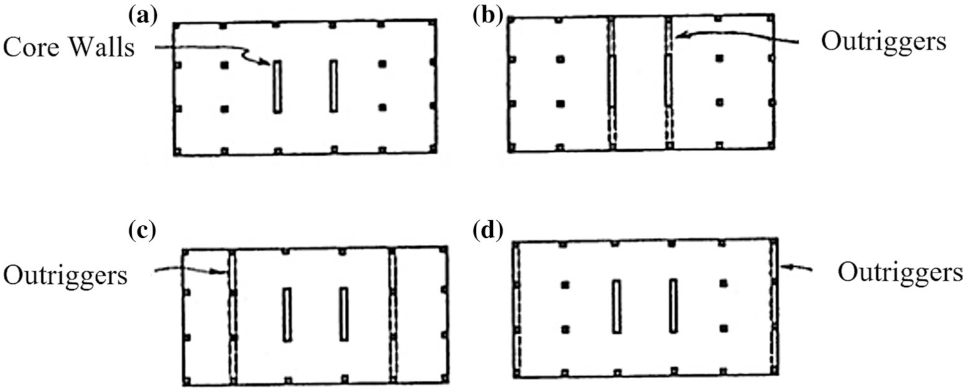

Figure 1. Different Forms of Outrigger structural systems a) Base Model (Core Only) b) Conventional Outrigger System c) Offset outrigger system d) alternate offset outrigger system

In contrast to a base model without outriggers and a traditional outrigger system, this study examines the seismic performance of a three-dimensional tall building model with an offset outrigger and belt truss system. STAAD.Pro highlights the advantages of sophisticated outrigger configurations for high-rise seismic resistance by evaluating important metrics like displacement, storey drift, and foundation shear.

2. Literature Review

Lateral forces from wind and earthquake loads present major design issues for tall buildings. To control base shear and inter-story drift, a variety of structural methods have been devised, including braced frames, shear walls, and tubular systems, as indicated by Walsh et al. [1]. Because they can increase overall stiffness and decrease overturning moments and deflections, outrigger and belt truss systems—which join the core to external columns—have become increasingly popular. Recent studies have investigated various outrigger configurations to enhance lateral performance under dynamic loads. Nair [2] introduced virtual outriggers via belt trusses in ETABS, showing belts alone can mimic base-level outrigger behaviour but require further validation in high seismic regions. Jain and Londhe [3] optimized belt-outrigger locations using Gray Wolf Optimization, recommending placements between 0.4H and 0.5H for symmetric structures. Haghollahi and Rahgozar [4] studied flexible outriggers via modal and pushover analyses, finding improved seismic damping but excluding belt trusses. Eltobgy [5] highlighted soil-structure interaction effects on belt and outrigger systems, noting a significant influence on lateral drift, though lacking fixed base comparisons. Dedeoğlu and Calayir [6] analysed torsional behavior improvements with belt trusses but did not extend to seismic validation. Taranath [7] empirically demonstrated better belt truss performance integrating basement levels, but without seismic simulation. Po Seng Kian [8] presented a case study combining earthquake and wind load effects. The findings indicated the need for updated drift limits under combined loading, though offset and irregular configurations were not included. Nigdikar and Shingade [9] used STAAD.Pro to assess RCC high-rise buildings with outrigger and belt truss systems. Their findings highlighted effective drift control when systems were positioned at mid-height. However, the study only considered regular-shaped structures. Patil and Mujawar [10] further confirmed the effectiveness of mid-height outrigger positioning and belt truss in drift control, though limitations remained regarding irregular plans and dynamic analysis. Khadka et al. [11] found optimal offset outrigger heights around 0.375H. Rahgozar and Sharifi [12] assessed the seismic performance of outrigger systems under soil-structure interaction using FEM and pushover analysis. They found that SSI reduced seismic resistance but did not explore belt truss integration. John and Kamath [13] examined the hybrid performance of outrigger systems under both wind and seismic loads using STAAD.Pro and response spectrum analysis. The results indicated optimal drift control at 0.45H. However, the study did not model belt truss interactions, which are essential for comprehensive system evaluation. Jain and Londhe [14] contributed insights into SSI effects and lateral resistance, emphasizing the need to include belt truss interactions and offset configurations.

Earlier reviews and analyses optimized multi-storey structures with dual outriggers in ETABS. They found that dual systems enhanced overall stability, but offset outriggers were not studied. Sattar and Livaoglu [15] examined the nonlinear seismic response of damped outrigger systems using time-history analysis. The study demonstrated improved damping in steel frames, although belt truss interaction was not analysed. Borah and Choudhury [16] reviewed various outrigger configurations in tall buildings. The summary offered insights into past research but lacked any form of modeling or experimental comparison. Daniel and Visuvasam [17] used STAAD.Pro to analyze the seismic behavior of steel outrigger systems.

Their study provided a practical assessment of performance under earthquake loading, confirming the effectiveness of outriggers. However, they did not compare the system with belt truss configurations, missing an opportunity to examine potential synergies. Kavyashree et al. [18] highlighted advancements in multi-storey outrigger systems, damping effects, and structural performance under seismic loading, while identifying research gaps with belting and offset systems. More recent investigations by Falamarz-Sheikhabadi and Ghafory-Ashtiany [19], Ahmed and Podder [20], Sheikh et al. [21], and Lin [22], has shown that the application of buckling-restrained braces (BRBs) in damped outrigger systems significantly improves the seismic performance of tall buildings through analytical and finite element studies. However, these studies did not consider belt truss components or the combined effects of seismic and wind loads, indicating areas for further research. Kolay et al. [23] reinforced the role of belt truss and damping devices in reducing drift and torsional effects, though some limited their scope by excluding combined seismic and wind load studies or belt truss components.

This review synthesizes key research trends, highlighting the importance of advanced outrigger configurations such as offset outriggers with belt trusses in optimizing lateral load resistance in tall buildings while identifying areas requiring further comprehensive seismic validation.

3. Methodology

The purpose of this study is to use STAAD.Pro V8i to assess the seismic performance of tall buildings that use an offset outrigger and belt truss system. Three separate structural models are created as part of the methodology: (1) the Base Model, which is a tall building without an outrigger system; (2) a building that has a traditional outrigger attached directly to the central core wall; and (3) a building that has a belt truss system and an offset outrigger. Every model is created in compliance with the applicable code (Table 1). Determining the structural geometry, allocating material properties, applying different loads (dead, live, seismic, and wind), and carrying out linear static and dynamic analysis are all steps in the modelling process (Fig. 2 – Fig. 7). While wind loads are determined in accordance with IS 875 (Part 3): 2015 [24], seismic parameters are based on IS 1893 (Part 1): 2016 [25]. Key performance parameters, including base shear, storey drift, and lateral displacement, are compared under various loading combinations.

Table 1. General details of the building considered for the study

No. of Storeys	G+40
Total length along X-direction	28 m
Number of Bays	5
Total length along Z-direction	18 m
Number of Bays	3
Grade of concrete used (f_{ck})	M40
Slab thickness	0.125 m
Shear wall thickness	0.23 m
Column size	0.5 m × 1 m
Beam size	0.3 m × 0.6 m
Typical storey height	3. 0 m
Grade of Concrete for column & shear wall	M40
Grade of steel	Fe500
Density of concrete	25 kN/m^2

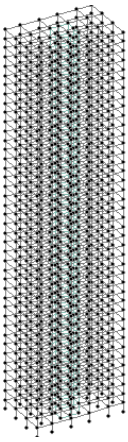

Figure 2. Overall 3D view of Base model

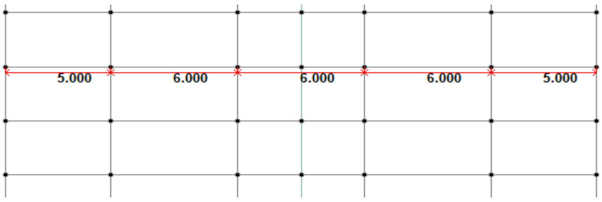

Figure 3. Spacing of Bays along X axis

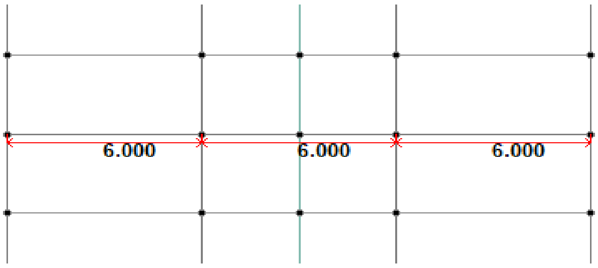

Figure 4. Spacing of Bays along Z axis

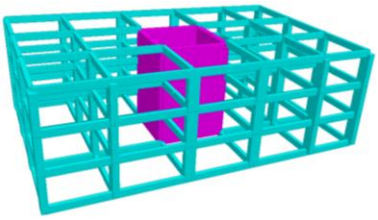

Figure 5. 3D view of 30th floor Base Structure

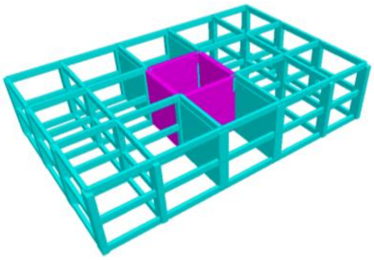

Figure 6. 3D view of 30th floor Conventional Outrigger

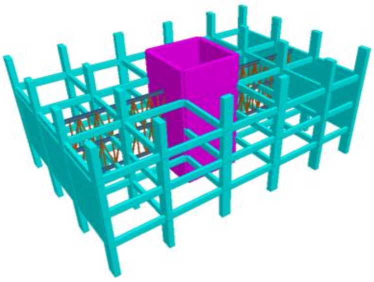

Figure 7. 3D view of 30th floor Offset Outrigger with belt truss system

Table 2. Properties of Outrigger and Belt truss

Property	Conventional Outrigger	Offset Outrigger
Location (Floor Level) [11]	30th Floor	30th Floor (Offset from Core)
Depth of outrigger (m) [16]	5.4 m	5.4 m
Width/Thickness (m)	0.5 m	0.5 m
Material	M40 Grade Concrete	M40 Grade Concrete
Connection Type	Direct connection to the core wall	Connected via belt truss
Belt Truss Depth [15]	NA	3.0 m
Belt Truss Material	NA	Structural Steel
Belt Truss Main Member	NA	ISMB350
Belt Truss Secondary Member	NA	ISA80x80x8
Purpose	Reduce lateral displacement and drift	Reduce lateral displacement with architectural clearance

Gravity loads are considered for analysis in accordance with Table 2, dead load consideration in accordance with IS 875 Part 1, and imposed load consideration in accordance with IS 875 Part 2, guaranteeing adherence to safety regulations and accurate load calculations (Table 3).

One technique for estimating how a structure will react to short-lived dynamic events, such as shocks and earthquakes, is reaction spectrum analysis. Because these loads are unpredictable, it is difficult to analyze their exact temporal history. These events cannot be regarded as stationary processes because of their brief duration. To determine the degree to which an event of this kind can excite a mode with a specified natural frequency, the response spectrum approach uses a particular kind of mode superposition and requires an input. This linear method is complicated because the manually calculated base shear frequently deviates from the base shear that the algorithm predicts, even though it can be determined manually. The structure, located in Seismic Zone IV with medium soil conditions, incorporates a lateral load-resisting system consisting of ductile RC structural walls, a conventional RC moment-resisting frame, and a semi-rigid diaphragm. Table 4 presents the response spectrum factors considered in STAAD.Pro, following the guidelines of IS 1893 Part 1 (2016) code (Fig. 8).

Table 3. Load Consideration for the Analysis

Type of Load	Load Calculation
Live load on a typical storey	3kN/m^2
Live load on a terrace	3kN/m^2
Floor finish on a typical floor	1.5kN/m^2
Floor finish on a roof	3kN/m^2
Wall Load on beams	11kN/m
Parapet load	5.69kN/m

Table 4. Response Spectrum Coefficients

Parameter	Value / Description	Code Reference
Seismic Zone Factor (Z)	0.16	IS 1893:2016, Table 3
Response Reduction Factor (R)	5 (SMRF)	Clause 7.2.6
Importance Factor (I)	1.5 (Residential/Commercial)	Table 8
Damping Ratio (ξ)	5%	Clause 3.4.2
Soil Type	Type II (Medium)	Table 1
Earthquake Load Direction	X and Z	-

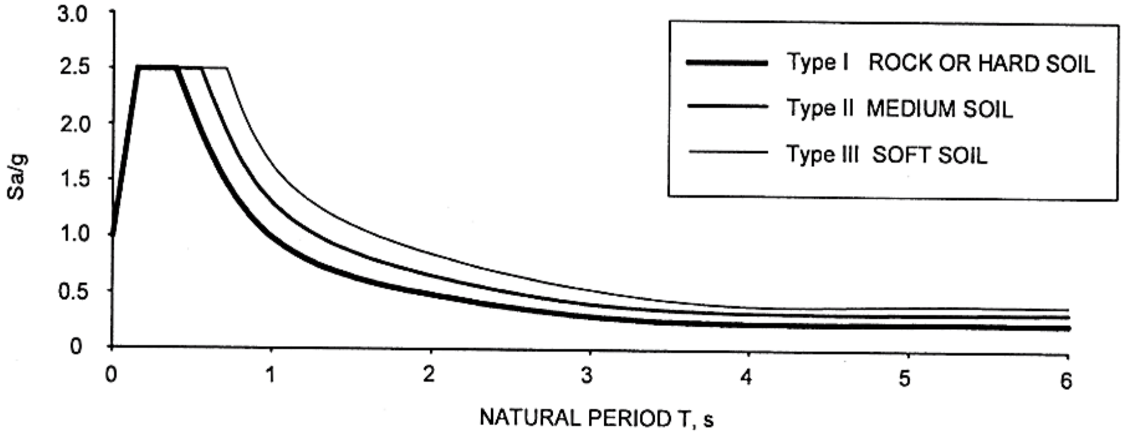

Figure 8. Acceleration Coefficient (Sa/g) [25]

Table 5. Wind Load Parameters

Parameter	Value / Description	Code Reference
Basic Wind Speed (Vb)	50 m/s	IS 875-3:2015, Fig. 1
Risk Coefficient (k1)	1	Table 1
Terrain Category	3	Clause 5.3.2
Topography Factor (k3)	1	Clause 5.3.3
Structure Class	B	Clause 5.3.4
Design Wind Pressure (p)	Calculated from p = $0.6 \times Vz^2$	Clause 5.4

To evaluate wind-induced forces on the tall building, wind design parameters are set in accordance with IS 875 (Part 3): 2015 rules (Table 5). Since the height-to-slenderness ratio is so large, wind impacts are essential in controlling lateral movement and overall serviceability. The parameters provide a precise prediction of design wind pressure at various heights by considering basic wind speed, terrain category, structure class, and topography factor. This makes it possible to simulate wind effects in the structural analysis in a realistic manner.

According to IS 875 (Part 3):2015, the basic wind speed, terrain category, topography factor, and gust response factor are used to compute the design wind pressure Pz at any height z. The calculated pressures for the current study indicate a slow rise from roughly 0.418 kN/m ^{2}at ground level to 0.966 kN/m ^{2}at the top of the 120 m structure. The foundation for applying wind loads in STAAD was established by calculating and tabulating the pressure values at discrete heights. Pro's use of the INT and HEIG arrays guarantees that wind effects are accurately represented in the structural analysis.

For structural analysis and design, load combinations were prepared in accordance with IS 456:2000 and IS 875 (Part 3):2015 for both Serviceability Limit State (SLS) and Ultimate Limit State (ULS) conditions. The SLS combinations ensure service-level performance without excessive deflection or vibration, whereas ULS combinations verify the safety of the structure under maximum design loads. The following load cases were considered:

STAAD is used to develop the building model by specifying the geometry, such as the building height, the number of stories, and the distance between bays, and by allocating material attributes like M30 concrete for the structure and structural steel for the outrigger components. There are cross-sectional specifications for outriggers, core walls, beams, and columns. According to the applicable codes, loads such as wind, dead, live, and seismic forces (in both X and Z directions) are applied. In accordance with IS 1893:2016, the dynamic analysis employs the linear Response Spectrum approach, and suitable load combinations are established for serviceability and ultimate inspections. Following the completion of the structural analysis, which guarantees stability and convergence, important output data is retrieved for assessment, including base shear values, inter-story drifts, and lateral displacements.

4. Results and Discussions

The impact of different shear wall configurations on a multi-story building's seismic response is investigated in relation to important variables such as base shear, storey displacement, and storey drift. Contour maps showing the resulting modal displacements, especially for translational and torsional modes, are analysed to optimize the positioning of shear walls. This chapter uses STAAD Pro to compare the performance of three structural designs for a tall, G+40 reinforced concrete building that is subjected to wind and seismic loads.

4.1. Mass Model Participation

Modal mass participation quantifies the fraction of a building’s total mass engaged in each vibration mode during seismic excitation, providing insight into the dynamic response. For the base model with only a core wall, the first modes in the X and Z directions capture about 68-69% of the mass, with cumulative participation exceeding 89% by mode 20, indicating significant lateral sway governed by fundamental modes (Fig. 9). The conventional outrigger system improves lateral stiffness, concentrating more mass participation in early modes and achieving nearly 90% participation within 20 modes, reflecting enhanced seismic behavior (Fig. 10). The offset outrigger with belt truss system exhibits similar high early-mode participation but offers a more uniform structural engagement due to the belt's stiffening effect, pushing dynamic response to higher frequencies and improving resilience (Fig. 11). Overall, mass participation analysis validates that outriggers and belt trusses efficiently redistribute seismic forces and optimize building dynamic behavior according to seismic code requirements.

The modal mass participation for the base model surpasses 89% within the first 20 modes in the Z-direction, meeting seismic design standards that typically require at least 90% mass participation. This indicates that the tall, flexible core-only structure primarily responds to lateral seismic excitation through a few dominant horizontal sway modes. The high participation of inertial forces in these initial modes emphasizes their importance for accurate dynamic design and safety evaluation.

The modal mass participation factors for the Conventional Outrigger system indicate how seismic forces activate the building's mass in each vibration mode along principal axes. For the X-direction, the first mode mobilizes approximately 69.52% of the building's mass, while in the Z-direction, the first mode has a similar high participation of about 69.37%. These dominant first modes represent the principal lateral sway responses of the building in perpendicular directions.

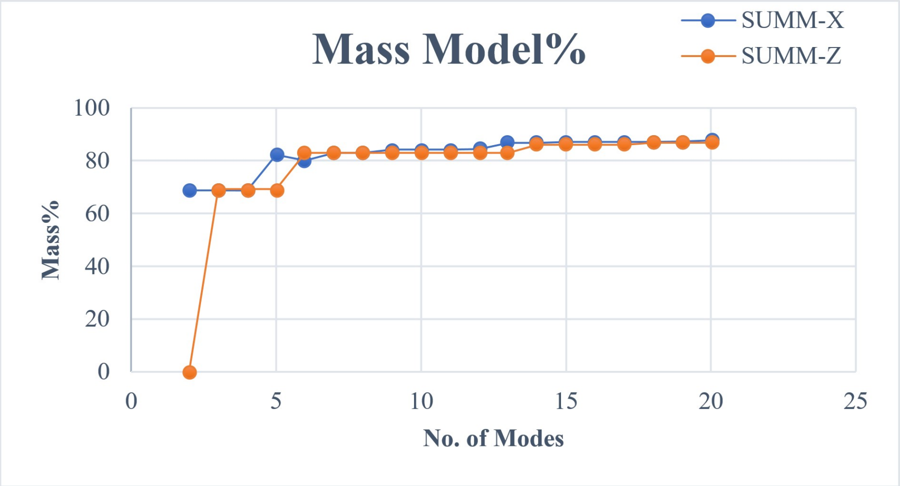

Figure 9. Graphical representation of mode shapes vs mass percentage- Base Model

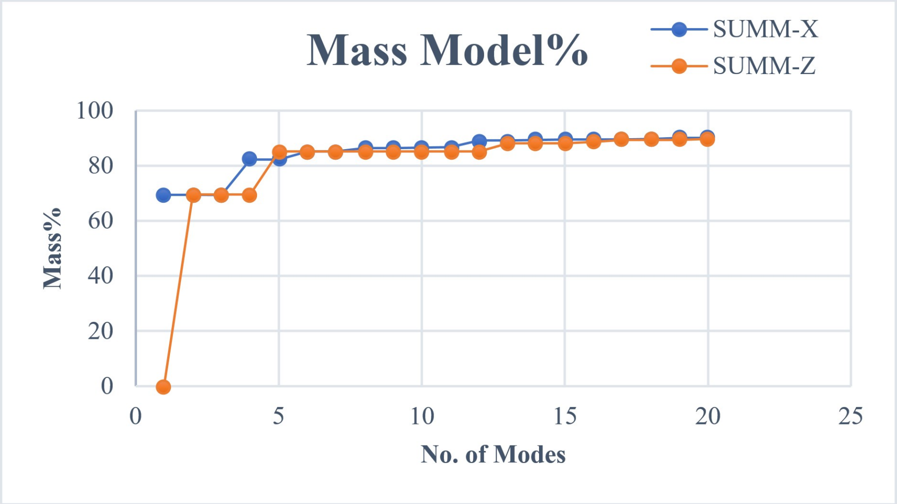

Figure 10. Graphical representation of mode shapes vs mass percentage- Conventional outrigger Model

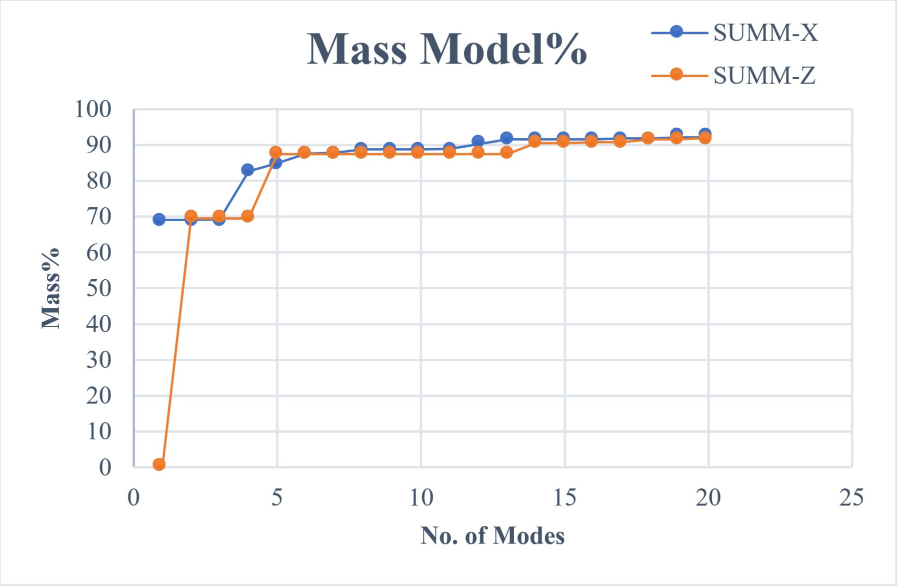

Figure 11. Graphical representation of mode shapes vs mass percentage- Offset outrigger Model

Subsequent modes contribute smaller increments of modal mass participation, with modes 4 and 5 adding approximately 12.83% and 15.7% in the Z and X directions respectively. The cumulative participation reaches around 89.7% to 90% by mode 20 in both X and Z directions (SUMM-X ≈ 89.74%, SUMM-Z ≈ 89.99%), fulfilling the IS 1893 requirement to include modes capturing at least 90% of the mass for seismic analysis. This pattern illustrates that the building's dynamic seismic response is governed largely by the first few low-frequency lateral sway modes. The Conventional Outrigger system increases lateral stiffness, concentrating more mass participation early in the modal spectrum compared to a base core-only model, which improves seismic behavior and response reliability.

The modal mass participation factors for the Offset Outrigger + Belt Truss system reveal the building's dynamic seismic response distribution in the X and Z directions. In the X-direction, the second vibration mode mobilizes approximately 69.5% of the building mass, while in the Z-direction, the first mode mobilizes about 69.17%. These values indicate that the fundamental lateral sway modes dominate seismic excitation, like the other configurations, but with refined dynamic behavior due to the belt truss and offset connection. Subsequent modes contribute additional participation, with modes 4 and 5 adding approximately 13.54% and 15.76% in the Z and X directions respectively. The cumulative participation percentage in both directions reaches about 89.75% in X and 89.97% in Z by mode 20, fulfilling seismic code requirements for dynamic analysis (which typically mandate capturing at least 90% of mass participation).

A crucial component of seismic analysis is modal mass participation, which is the percentage of a building's total mass that is engaged in various vibration modes under dynamic loading. To prevent underestimating lateral displacements, drifts, and base shear, which could result in dangerous designs, effective modeling requires at least 90% cumulative mass participation in the primary directions. Mass involvement demonstrates the effectiveness of outrigger and belt truss systems in tall buildings by redistributing stiffness and affecting dynamic behavior. Outriggers improve seismic response and alter modal forms by connecting the core to exterior columns. By assessing mass involvement, one can verify reaction spectrum or time-history analyses, compare conventional and offset outrigger systems, and make sure the structural model accurately depicts behavior and conforms to seismic standards.

4.2. Base Shear Response for Different Structural Configurations

The observed increase in base shear with the introduction of outrigger systems can be attributed to the improved stiffness and redistribution of seismic forces (Fig. 12). The base model, with only a core wall, relies solely on the central core for lateral resistance, resulting in the lowest base shear values. The conventional outrigger at Level 30 connects the core to perimeter columns, effectively mobilizing the entire structural width, thereby increasing stiffness and attracting higher seismic forces. The offset outrigger + belt truss configuration further enhances this mechanism by distributing forces more evenly along the height and by engaging additional columns via the belt truss, leading to the highest base shear among the three configurations. While higher base shear indicates greater force demand on the foundation and structural members, it also reflects reduced lateral deflections, which is a desirable characteristic for serviceability and stability in tall buildings. These results are consistent with the general understanding in tall building design: as stiffness increases, base shear demand also increases due to reduced fundamental period and increased participation of higher modes. Designers must balance stiffness enhancements with the resulting increase in base shear to achieve an optimal seismic performance.

4.3. Overturning Moment

The Overturning moment in a building structure refers to the rotational force generated due to lateral loads such as wind or earthquake forces acting on the structure. This moment tends to cause the building to twist or topple, and it is a critical parameter for assessing the stability and safety of tall buildings. Outrigger systems, including conventional outriggers and offset outriggers with belt trusses, are structural elements designed to enhance the lateral stiffness of a building by connecting the central core to the exterior columns. This connection effectively reduces the overturning moments by restraining the core's lateral displacement, thereby improving the overall stability and reducing the risk of structural failure. Compared to a base model without outriggers, buildings equipped with outrigger systems demonstrate significantly lower overturning moments, with offset outriggers typically providing the greatest reduction due to their enhanced stiffness and load distribution capacity (Fig. 13). Proper design and placement of outriggers are vital to optimize these benefits and ensure the structural integrity of high-rise buildings under lateral loading conditions.

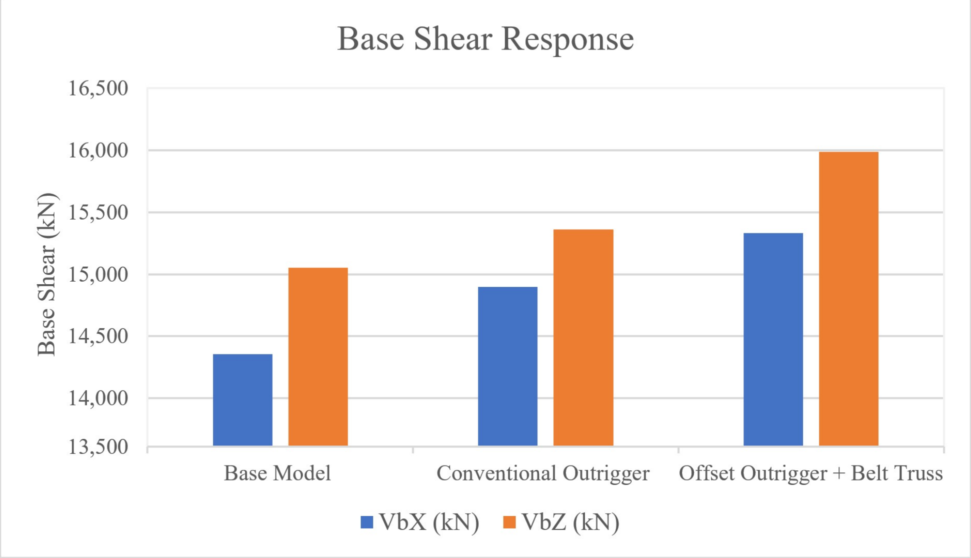

Figure 12. Base shear response of the structure considered in the study

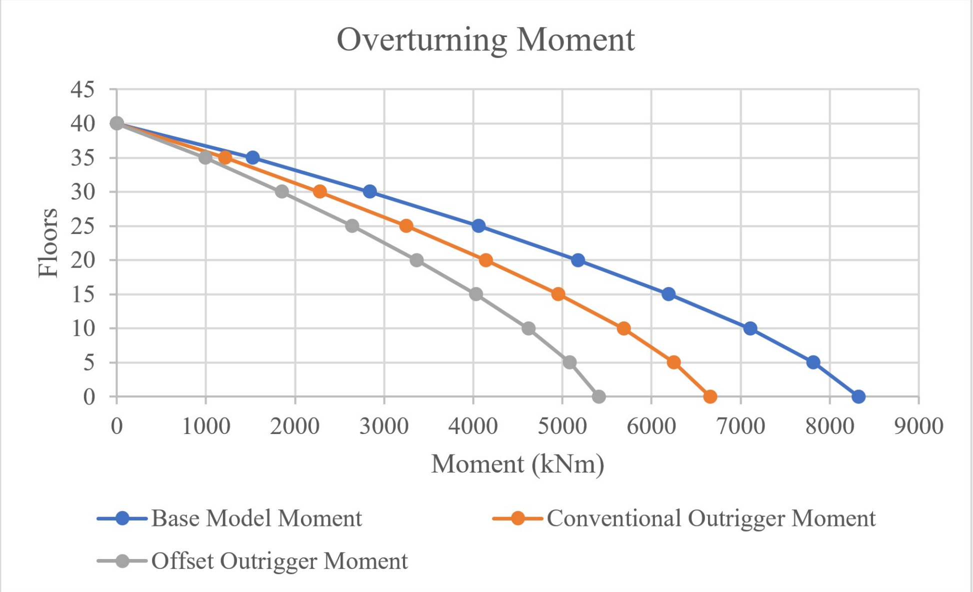

Figure 13. Overturning Moment of the models analysed

4.4. Displacement

Storey displacement is the lateral movement experienced by each floor level of a structure under lateral loads such as seismic or wind excitation. It is measured relative to the base level and is a critical indicator of structural stiffness, serviceability performance, and occupant comfort. In tall buildings, excessive displacement can cause damage to non-structural elements (cladding, partitions, glazing) and affect human perception of motion. IS 1893:2016 and IS 16700:2017 [26] indirectly control displacement by imposing drift limits, but engineers also target displacement reductions for performance and comfort. The displacement rises nonlinearly with altitude. Because of the core wall system's increased flexibility, the Base Model curve is the steepest. At and beyond Level 30, the conventional outrigger curve is flatter, indicating increased stiffness brought on by the outrigger movement.

The offset curve shows the best top-level control since it is the flattest. According to the Code Provisions, a structure's maximum top displacement cannot exceed h/200, where h is the overall height, or 123 meters, and 657 mm is the limiting maximum displacement. All three of the model displacements in this instance fall inside the bound. According to the Code Provisions, a structure's maximum top displacement cannot exceed h/200 [27], where h is the overall height, or 123 meters, and 657 mm is the limiting maximum displacement. All three of the model displacements in this instance fall inside the bound (Fig. 14). The displacement profile of the Base Model reveals increasing lateral drift that builds up with height, reaching its maximum at the roof at 285.4 mm. Larger rotations and increased top displacement result from the central core bearing the full overturning moment due to the lack of supplementary lateral systems. With a peak top-floor displacement of roughly 285–290 mm, the Base Model shows the largest displacement. Reduced lateral stiffness is seen by the almost linear displacement curve. Top-floor displacement is reduced by conventional outriggers to roughly 205 mm, demonstrating a noticeable improvement because of the outrigger system's increased stiffness.

With the lowest top-floor displacement of about 175 mm, the offset outrigger performs better at reducing lateral wobble. The highest levels of the curve exhibit a tiny plateau, indicating increased stiffness in the upper stories.

According to the findings, adding an outrigger system greatly increases lateral stiffness and decreases displacement. Additionally, by providing an extra ~15% displacement reduction over the standard arrangement and ~40% reduction over the base model, the offset outrigger with belt truss layout performs better than the traditional outrigger.

4.5. Storey Drift Response for Different Structural Systems

The relative horizontal movement between two successive floors brought on by lateral (seismic or wind) pressures is known as storey drift. In tall buildings, excessive drift is a crucial serviceability and safety criterion, since it can cause occupant discomfort and damage to non-structural elements like cladding and partitions. The 30th floor of your G+40 structure is crucial because, according to IS 1893:2016, the drift limit for most structures is 0.004 times the storey height, and the outrigger level is frequent where the most noticeable variation in drift behavior occurs (Fig. 15).

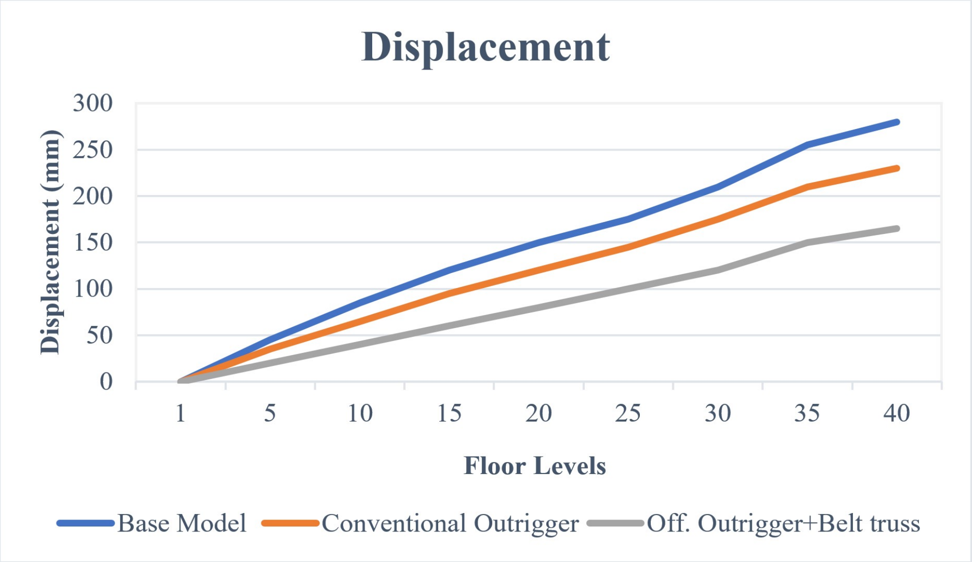

Figure 14. Storey Displacement response of the structure considered in the study

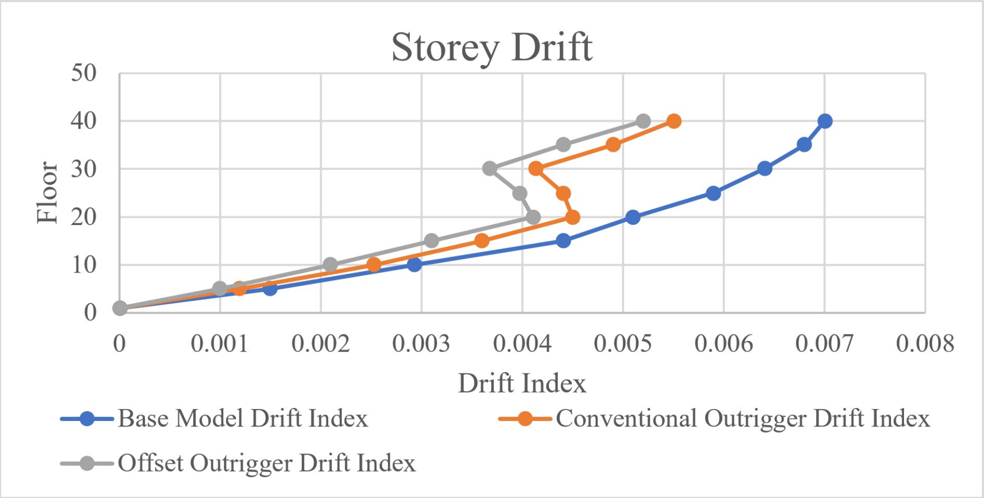

Figure 15. Storey Drift response of the structure considered in the study

Base Model: Of the three systems, the base model exhibits the greatest storey drift at the 30th level, which is indicative of the core's concentration of overturning demand. Greater inter-story movement is possible due to the lack of any external constraints, possibly surpassing serviceability and code drift limits, and raising the possibility of non-structural damage.

Traditional Outrigger: Installing a direct outrigger at the 30th level significantly lowers storey drift there, by about one-third when compared to the base model. By coupling the core and perimeter columns, the outrigger mechanism limits core rotation at the outrigger floor and redistributes lateral forces. At Level 30, this constraint causes a noticeable "kink" or decrease in the drift profile, which is in line with analytical and experimental results reported in the literature. Offset Outrigger: The offset outrigger with belt truss system achieves the lowest drift at the 30th floor, further improving performance over the conventional arrangement. The belt truss ties a ring of perimeter columns together, enhancing compatibility and distributing forces, which flattens the drift profile and provides smoother restraint across multiple storeys. The results show a nearly 40% reduction in maximum drift at Level 30 compared to the base model, and a notable improvement over the conventional outrigger.

All three structural systems are evaluated against the IS 1893 drift limit of 0.004 times the storey height (h). Both outrigger systems, especially the offset configuration, generally maintain maximum lateral drift within this code limit, offering better safety margins for cladding and partitions and minimizing serviceability issues, particularly at the critical outrigger floors in tall buildings. The base model tends to exhibit the highest drift with minimal restraint, making it less suitable for tall structures. The conventional outrigger effectively controls drift at the outrigger level but causes a localized kink that requires careful design. In contrast, the offset outrigger with belt truss distributes drift reduction more evenly across multiple floors, yielding superior serviceability and enhanced structural resilience.

5. Conclusions

The comparative study between the base model, conventional outrigger system, and offset outrigger with belt truss has demonstrated the significant role of outrigger systems in enhancing the seismic performance of tall buildings. The results clearly indicate that both conventional and offset configurations substantially reduce lateral displacement, storey drift, and improve base shear capacity when compared to the Base model. Among the configurations studied, the offset outrigger combined with a belt truss achieved the highest performance improvement, owing to the enhanced engagement of peripheral columns and better distribution of lateral forces.

The offset outrigger with belt truss system effectively reduces lateral forces due to wind and seismic loads by enhancing the stiffness and load distribution capability of the structure more efficiently than the conventional outrigger or base model. By connecting the central core to the exterior columns asynchronously with the belt truss, this system provides additional restraint against lateral displacements and rotations, thereby significantly reducing overturning moments and inter-story drifts. This improved structural interaction leads to better control of building sway and deformation, resulting in enhanced stability and safety under lateral loading.

These findings reinforce the practical relevance of combining offset outriggers with belt trusses, particularly in projects where direct connection to the core is not feasible. Future research may explore the integration of such systems under time history analysis and in irregular structural geometries to further validate their effectiveness in diverse design conditions.

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