

Comparative Seismic Performance of High-Rise RCC Buildings with Outrigger-Belt Truss Systems

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ABSTRACT

This study evaluates the seismic and wind performance of a G+30 reinforced concrete building using four structural systems: Core Shear Wall, Radial Outrigger Belt Truss, Perimeter Belt Truss, and Combined Outrigger–Perimeter Belt Truss. The models were analyzed in ETABS using Response Spectrum Analysis as per IS 1893 (Part 1): 2016 and wind analysis as per IS 875 (Part 3): 2015. Structural performance was assessed based on base shear, overturning moment, storey displacement, and storey drift. The results indicate that the Combined Outrigger and Perimeter Belt Truss System (M4) provides the best overall performance by significantly reducing displacement and drift while improving lateral stiffness. The study demonstrates that integrating outrigger and belt truss systems is an effective solution for enhancing the seismic and wind resistance of high-rise reinforced concrete buildings.

Keywords: Outrigger Truss, Belt Truss, Core Shear Wall, Response Spectrum Analysis, ETABS, Storey Displacement, Storey Drift, High-Rise Building, Seismic Zone IV.

CHAPTER 1: INTRODUCTION

1.1 General

The outrigger system is one of the most efficient structural systems used in medium and high-rise buildings to improve resistance against lateral loads such as wind and earthquakes. It consists of one or more horizontal stiff structural elements, known as outriggers, that connect the central core of the building to the exterior perimeter columns. These outriggers may be constructed using reinforced concrete walls, steel trusses, or deep beams. When lateral loads act on a building, the central core tends to bend and rotate. The outrigger restrains this rotation by transferring a portion of the overturning moment from the core to the perimeter columns. The exterior columns develop axial tension and compression forces, which create a counteracting moment that enhances the overall stiffness and stability of the structure. This interaction

significantly reduces lateral displacement, inter-storey drift, and core rotation.

1.2 High-Rise Structures

A high-rise structure is a building whose height significantly influences its design, construction, and structural behavior. Unlike low-rise buildings, high-rise structures are more susceptible to lateral forces due to their greater height and slenderness. Rapid urbanization has increased the demand for tall buildings, which provide efficient solutions for land use in densely populated areas. Buildings taller than approximately 35–40 meters are commonly classified as high-rise structures. As height increases, lateral loads become more critical than gravity loads. Wind loads can cause excessive sway, while earthquake forces generate dynamic responses that may lead to significant damage. Storey drift (relative lateral displacement between consecutive floors) is a critical parameter, as excessive

drift can damage structural and non-structural components.

1.3 Slender Buildings

A slender building is characterized by a high height-to-width ratio. The slenderness ratio is defined as the ratio of total building height to its least plan dimension. According to Awida (2011), this ratio significantly influences structural performance. Ilgin (2022) reported that many supertall buildings exhibit slenderness ratios ranging from 7 to 15, indicating the increasing importance of lateral load resistance as the aspect ratio increases.

1.4 Outrigger and Belt Wall System

An Outrigger and Belt Wall System is one of the most efficient lateral load-resisting systems. It consists of a central reinforced concrete core connected to exterior perimeter columns through stiff horizontal outriggers. A belt wall is provided around the perimeter at the outrigger level to distribute forces efficiently. According to Smith and Coull (1991) and Taranath (2016), the outrigger system transforms the behavior of a tall building from simple cantilever action into a combined core-column structural system, resulting in improved efficiency and stability.

Components:

1. Central Core: Primary vertical element (shear walls around elevators/staircases).
2. Outrigger Wall: Stiff horizontal element connecting core to columns.
3. Belt Wall: Horizontal wall around perimeter distributing forces.
4. Exterior Columns: Develop axial tension/compression to resist overturning.

Mechanism:

- Without outriggers: Entire overturning moment resisted by core; large displacement.
- With outriggers: Outrigger forces perimeter columns to resist rotation; compression on one side, tension on the opposite side; creates counteracting moment.

1.5 Methods of Analysis

Structural analysis methods include Static Analysis (Linear Static, Equivalent Static) and Dynamic Analysis (Response Spectrum Analysis, Time History Analysis). For high-rise buildings, dynamic analysis methods such as Response Spectrum Analysis (RSA) are preferred

because they accurately capture the effects of wind and earthquake loads. RSA evaluates the maximum response of individual vibration modes from a design response spectrum. Modern software such as ETABS uses finite element formulations.

1.6 Codal Provisions

- IS 1893 (Part 1): 2016 – Criteria for Earthquake Resistant Design.
- IS 875 (Part 1, 2, 3): 2015 – Design Loads (Dead, Live, Wind).
- IS 456: 2000 – Plain and Reinforced Concrete Code.

Zone Factor (IS 1893): $Z = 0.24$ for Seismic Zone IV (used in this study).

Importance Factor (I) = 1.2 (for important buildings).

Response Reduction Factor (R) = 5 (Special Moment Resisting Frame).

Wind Load Calculation (IS 875 Part 3: 2015):

$$V_z = V_b \times K_1 \times K_2 \times K_3 \times K_4$$

$$P_z = 0.6 \times V_z^2$$

CHAPTER 2: LITERATURE REVIEW

2.1 Key Findings from Previous Studies

Nair R. S. (1998): Studied belt trusses and virtual outriggers. Concluded that outriggers significantly reduce core rotation and improve lateral stiffness.

Po Seng Kian and Frits Torang Siahaan (2001): Found that outriggers considerably reduce top-storey displacement. Effectiveness depends on location and stiffness.

Bayati, Mahdikhani and Rahaei (2008): Multiple outriggers perform better than single outrigger. Proper positioning maximizes structural efficiency.

Herath, Haritos and Ngo (2010): Stiffness of outrigger beam plays a crucial role in controlling structural response.

Kamgar and Rahgozar (2017): Optimum outrigger location is near the upper third of

building height for maximum reduction in displacement and drift.

Sangtiani et al. (2017): Compared Conventional, Shear Wall, and Core Outrigger systems for G+53 building. Outrigger system showed minimum displacement, lower structural weight, and enhanced stiffness – most efficient for tall buildings.

Shelke and Kawade (2022): Compared Shear Wall, Outrigger, and Tube-in-Tube systems for G+50 building. Tube-in-Tube best for drift; Outrigger best for reducing base shear.

2.2 Research Gap Identified

Despite extensive research, limited studies have comparatively evaluated Radial Outriggers, Perimeter Belt Trusses, and their COMBINATION within the same G+30 RC building under identical loading and modeling conditions using RSA and Wind analysis as per latest IS codes. This study addresses that gap.

CHAPTER 3: OBJECTIVES

The primary objective of this research is to evaluate the seismic performance of a G+30 reinforced concrete high-rise building incorporating different outrigger truss configurations using Response Spectrum Analysis in ETABS.

Specific Objectives:

1. To develop and analyze four structural models: Core Shear Wall (M1), Radial Outrigger Belt Truss (M2), Perimeter Belt Truss (M3), and Combined Outrigger and Perimeter Belt Truss (M4) under identical loading and geometric conditions.
2. To compare Base Shear, Overturning Moment, Vertical Reactions, Storey-wise Displacement, and Storey Drift.
3. To assess the improvement in lateral stiffness and overall stability achieved by each system.
4. To identify the most effective outrigger truss configuration and provide recommendations for earthquake-resistant design in Seismic Zone IV.

CHAPTER 4: METHODOLOGY

4.1 Building Model Specifications

PARAMETER	VALUE
Total Building Height	90 m (G+30)
Typical Storey Height	3.0 m

Base Storey Height	3.0 m
Plan Dimensions	24 m (Y) × 40 m (X)
No. of Bays (X × Y)	5 × 3 (each 8 m)
Concrete Grade	M50
Steel Grade	Fe500
Column Size (G to 10th Floor)	1200 mm × 1200 mm
Column Size (11th to 20th Floor)	900 mm × 900 mm
Column Size (21st to Terrace)	650 mm × 650 mm
Beam Size	700 mm × 400 mm
Slab Thickness	190 mm
Core Shear Wall Thickness	300 mm
Floor Finish Load	1.5 kN/m ²
Live Load (Typical Floors)	3.0 kN/m ²
Live Load (Roof)	1.5 kN/m ²
Soil Condition	Hard Rock (Type I)
Damping Ratio	5%
Response Reduction Factor (R)	5.0
Importance Factor (I)	1.2
Seismic Zone	IV (Z = 0.24)
Software Used	ETABS 22

4.2 Four Cases (Models) Analyzed

MODE L	DESCRIPTIO N	OUTRIGGER/BEL T LOCATION
M1	Core Shear Wall only (Conventional)	No outrigger
M2	Core + Radial Outrigger Truss (4 sides connecting core to columns)	14th Storey
M3	Core + Perimeter Belt Truss (only	14th Storey

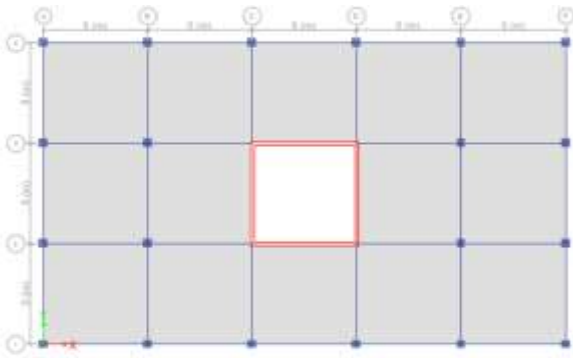
	along building perimeter)	
M4	Core + Radial Outrigger + Perimeter Belt (COMBINED)	14th Storey

4.3 Load Combinations (as per IS 1893)

- 1) 1.5 (DL + LL)
- 2) 1.2 (DL + LL ± EL)
- 3) 1.5 (DL ± EL)
- 4) 0.9 DL ± 1.5 EL

4.4 Analysis Procedure in ETABS

Fig.4.1 Plan of Structure



Step 1: Model initialization and grid definition.

Step 2: Define material properties (M50 concrete, Fe500 steel).

Step 3: Assign section properties (beams, columns, slab, core wall).

Step 4: Assign fixed support at base.

Step 5: Define modal cases and response spectrum function as per IS 1893.

Step 6: Assign loads (DL, LL, Wind, Seismic).

Step 7: Perform Response Spectrum Analysis and Wind Analysis.

Step 8: Extract results (Reactions, Base Shear, Overturning Moment, Displacement, Drift).

Step 9: Compare and analyze results.

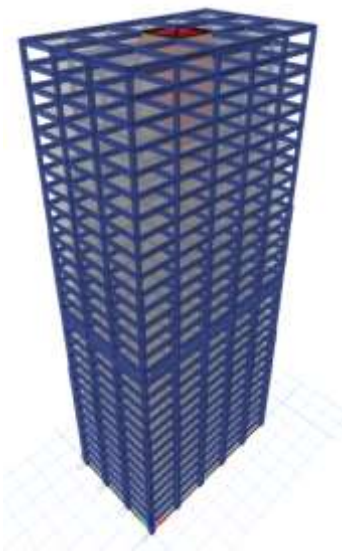


Fig. 4.2 Rendered View Of Modelling in ETAB22.

CHAPTER 5: RESULTS

TABLE 5.1: MAXIMUM SUPPORT REACTIONS (kN)

MODEL	FZ (kN)	OBSERVATION
M1	782,195.26	High reaction (core carries most load)
M2	627,823.36	LOWEST (radial outriggers redistribute forces efficiently)
M3	784,354.48	Similar to M1
M4	785,973.89	HIGHEST (combined system engages all columns)

Observation: M4 has the highest reaction, indicating maximum load transfer to foundation.

M2 has the lowest, as outriggers effectively redistribute core forces to exterior columns without overloading the foundation.

TABLE 5.2: BASE SHEAR COMPARISON

LOAD TYPE	M1 (kN)	M2 (kN)	M3 (kN)	M4 (kN)
RSA-X	3,920.64	4,231.99	4,104.39	4,226.71
Wind-X	4,168.11	4,168.11	4,168.11	4,168.11
RSA-Y	3,896.59	4,089.52	3,995.72	4,094.11

Wind-Y	7,926.44	7,926.44	7,926.44	7,926.44
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Observation: M2 and M4 attract the HIGHEST base shear under RSA, confirming they are the stiffest systems, engaging more structural mass. Wind base shear is identical for all models since external geometry and mass are identical (only internal structural system changes).

TABLE 5.3: OVERTURNING MOMENTS

LOAD TYPE	M1 (kN-m)	M2 (kN-m)	M3 (kN-m)	M4 (kN-m)
RSA-X	180,141	209,372	199,768	211,165
Wind-X	203,136	203,136	203,136	203,136
RSA-Y	169,618	188,501	182,471	193,010
Wind-Y	386,302	386,302	386,302	386,302

Observation: M4 produces the HIGHEST overturning moment, meaning it provides the greatest resistance to the "toppling" effect of lateral loads.

TABLE 5.4: MAXIMUM STOREY DISPLACEMENT (ROOF LEVEL - STORY 30)

LOAD TYPE	M1 (mm)	M2 (mm)	M3 (mm)	M4 (mm)
RSA-X	26.418	24.166	24.528	23.558
Wind X	27.845	21.856	23.279	21.156
RSA-Y	28.603	26.802	26.843	25.838
Wind-Y	60.827	50.977	52.907	48.080

TABLE 5.5: STOREY DRIFT

PERMISSIBLE LIMIT (IS 1893): $0.004 \times \text{Storey Height}$
 $\text{Height} = 0.004 \times 3000 \text{ mm} = 12 \text{ mm}.$

Observation:

- ALL models (M1 to M4) are well within the safe limit.
- M4 exhibits the minimum drift, confirming superior inter-storey deformation control.

- Peak drift occurs at intermediate storeys (around Story 15-20) for all models.

- This confirms structural safety of all configurations.

CHAPTER 6: CONCLUSIONS

Based on the results obtained from Response Spectrum Analysis and Wind Load Analysis of the G+30 reinforced concrete building with four different lateral load-resisting systems, the following conclusions are drawn:

1. The Combined Outrigger and Perimeter Belt Truss System (M4) demonstrates the BEST overall structural performance among all four models, with the lowest storey displacement and drift under both seismic and wind loading.
2. Compared to the conventional core shear wall system (M1), Model M4 reduces RSA roof displacement by 10.83% in the X-direction and 9.67% in the Y-direction. Under wind loading, the reduction is even more significant at 24.02% in the X-direction and 20.96% in the Y-direction.
3. The incorporation of outrigger and belt truss systems significantly increases lateral stiffness. M2 and M4 attract higher base shear under RSA, confirming that stiffer structures engage more seismic mass but provide better resistance against lateral forces.
4. The overturning moment is maximum for Model M4 (Combined system), indicating its superior ability to resist the "toppling" effect induced by lateral loads.
5. Storey drift values for all four models are well within the permissible limit of 12 mm specified by IS 1893 (Part 1): 2016. However, Model M4 exhibits the minimum drift, ensuring superior serviceability and reduced non-structural damage during earthquakes.
6. The combined action of radial outriggers and perimeter belt trusses in Model M4 effectively distributes lateral forces to the exterior columns, reduces core rotation, and enhances the global stiffness of the structure.
7. Based on the overall evaluation, the performance ranking of the structural systems is: $M4 > M2 > M3 > M1$.
8. For high-rise reinforced concrete buildings (G+30 and above) located in Seismic Zone IV, the Combined

Outrigger and Perimeter Belt Truss System (M4) is highly recommended as the most efficient lateral load-resisting system for ensuring safety, stability, and serviceability.

CHAPTER 7: FUTURE SCOPE

1. The present study can be extended to super high-rise buildings (G+40, G+50, and taller) to evaluate the effectiveness of outrigger systems at greater heights.
2. Future research may investigate the influence of different outrigger locations and multiple outrigger levels to determine the optimum configuration.
3. The study can be expanded by considering different seismic zones, soil conditions, and importance factors.
4. Time History Analysis using recorded earthquake ground motions can be performed for more realistic dynamic behavior assessment.
5. The performance of steel, composite, and reinforced concrete outrigger systems can be compared to identify the most efficient and economical solution.
6. Nonlinear static (pushover) analysis and nonlinear time history analysis may be conducted to evaluate post-elastic behavior and collapse performance.
7. A detailed cost-benefit analysis considering construction cost and material consumption can be performed for economical optimization.
8. The use of advanced vibration control devices (Tuned Mass Dampers, Viscous Dampers, Base Isolation) in combination with outrigger systems can be investigated.
9. Optimization techniques using Artificial Intelligence, Machine Learning, or Genetic Algorithms may be applied to determine optimum outrigger size and location.

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