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Effects of Story Drift and Building Deflection due to Wind and Earthquake Forces in the Presence of Multiple Level Outriggers

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Abstract: ***The rapid growth of urbanization in India has led to the construction of increasingly tall and slender buildings, where control of lateral displacements due to wind and earthquake forces becomes a governing design criterion. Outrigger–belt truss systems are widely adopted in tall buildings to enhance lateral stiffness and reduce excessive story drift and overall building deflection. This study evaluates the effects of story drift and lateral deflection in tall reinforced concrete buildings subjected to wind and seismic loads, with special emphasis on the structural performance of multiple-level outrigger systems. A three-dimensional analytical model of a high-rise building is developed and analyzed using structural analysis software. Wind loads are calculated in accordance with IS 875 (Part 3): 2015, while seismic forces are evaluated using the response spectrum method as per IS 1893 (Part 1): 2016. The overall structural configuration, drift limits, and serviceability criteria are checked in compliance with IS 16700: 2023. Various structural models are considered, including a core-only system and systems with single and multiple outriggers placed at different heights along the building elevation.***

Keywords: Tall Buildings, Multiple-Level Outriggers, Story Drift, Lateral Deflection, Outrigger–Belt Truss System, Structural Performance.

1. Introduction

Rapid urbanization and the increasing scarcity of land in metropolitan areas have led to the construction of increasingly tall and slender buildings. As the height of buildings increases, the effects of lateral loads induced by wind and earthquakes become more significant than gravity loads in governing structural design. Excessive lateral displacement, inter-storey drift, and overturning moments not only affect structural safety but also reduce occupant comfort and serviceability. Therefore, providing an efficient lateral load-resisting system is one of the major challenges in the design of high-rise buildings.

Among the various structural systems developed for tall buildings, the outrigger system has emerged as one of the most efficient solutions for enhancing structural stiffness and improving lateral load resistance. An outrigger system consists of rigid horizontal members, such as reinforced concrete walls, deep beams, or steel trusses, which connect the central structural core to the perimeter columns. When subjected to wind or seismic loading, the outriggers transfer overturning forces from the central core to the exterior columns, enabling the entire structural system to participate in resisting lateral loads. This mechanism significantly reduces building sway, increases lateral stiffness, and improves the overall structural performance.

The structural efficiency of outrigger systems depends on several parameters, including the number of outriggers, their vertical location, stiffness, and interaction with the central core and perimeter columns. Conventional systems generally employ one or two outriggers placed at selected heights, while modern tall buildings increasingly adopt multiple-outrigger configurations to achieve greater reductions in roof displacement and inter-storey drift. The inclusion of belt trusses further enhances the effectiveness of the system by distributing axial forces among the perimeter columns and increasing the overall overturning resistance.

Previous research has demonstrated that outrigger systems can substantially improve the seismic and wind performance of tall buildings by reducing lateral displacement, controlling storey drift, and decreasing core bending moments. However, the effectiveness of different outrigger arrangements depends on their location and configuration, and no universally accepted design guideline exists for selecting the optimum number and placement of outriggers. Consequently, comparative studies on different outrigger configurations remain essential for developing economical and efficient structural designs.

In the present study, the seismic performance of a reinforced concrete high-rise building is evaluated using three different outrigger configurations: (i) Bottom-Level Outrigger, (ii) Bottom + Mid-Level Outrigger, and (iii) Bottom + Mid + Top-Level Outrigger**.** The structural models are analyzed using ETABS under the provisions of IS 1893 (Part 1): 2016**,** and their performance is assessed in terms of maximum lateral displacement, inter-storey drift, base shear, fundamental time period, and modal participation factors. The comparative evaluation aims to identify the most effective outrigger configuration capable of providing improved seismic performance while maintaining structural efficiency.

The findings of this study are expected to contribute to the understanding of multi-outrigger systems in reinforced concrete tall buildings and provide practical guidance for structural engineers in selecting suitable outrigger configurations for earthquake-resistant design.

2. Literature Review

Alaa et al. (2022) [1] conducted a comprehensive numerical investigation on the seismic behavior of reinforced concrete tall buildings equipped with outrigger systems. The study evaluated the influence of the number, location, and stiffness of outriggers on lateral displacement, inter-storey drift, base shear, and overturning moment using three-dimensional finite element analysis. Different configurations, including single, double, and triple outriggers, were investigated under seismic loading. The results demonstrated that increasing the number of outriggers significantly enhanced lateral stiffness and reduced roof displacement and drift. However, the study mainly emphasized optimization of outrigger location and did not extensively compare practical outrigger arrangements used in design

Hirani et al. (2021) [2] compared the seismic and wind performance of outrigger and flag-wall systems in high-rise reinforced concrete buildings having regular and irregular plans. ETABS software was used to perform response spectrum, time-history, and wind analyses on G+59, G+69, and G+79 storey buildings located in Seismic Zones IV and V. The study concluded that both outrigger and flag-wall systems substantially reduced roof displacement, storey drift, and base shear compared with conventional core-only buildings. Although flag-wall systems provided greater architectural flexibility, conventional outriggers exhibited superior structural performance under seismic loading.

Kim and Hong (2019) [3] investigated the influence of outrigger location and stiffness on the lateral response of tall buildings subjected to combined wind and earthquake loading. Through three-dimensional numerical modeling, the authors observed that optimum outrigger locations generally occur near one-third and two-thirds of the building height. They also reported that outrigger stiffness significantly affects force transfer between the core and perimeter columns. Nevertheless, the authors highlighted the absence of a unified design guideline for determining optimum outrigger stiffness in practical applications.

Chung and Sunu (2015) [4] presented a comprehensive review of outrigger systems used in Korean super-tall buildings. The study discussed structural behavior, construction techniques, and practical challenges associated with outrigger construction. The authors reported that nearly three-fourths of recently constructed super-tall buildings adopted outrigger systems due to their superior efficiency in resisting overturning moments and controlling lateral drift. The study also emphasized differential column shortening as a major construction issue requiring careful detailing during implementation.

Lee et al. (2012) [5] investigated the seismic performance of twisted steel tall buildings provided with outrigger systems. Buildings with different twist angles were analysed under seismic loading. The study showed that increasing the twist angle reduced global stiffness and altered seismic response characteristics. Although twisted geometries provide aerodynamic advantages under wind loading, their seismic behavior requires further investigation due to the lack of specific design provisions.

Chen and Chang (2008) [6] examined the influence of floor slab stiffness on outrigger-braced tall buildings. Unlike earlier analytical studies that assumed rigid diaphragms, the authors incorporated slab stiffness into analytical and numerical models of a 60-storey building. Their findings indicated that floor slab stiffness significantly influences drift behavior and force transfer. The optimum locations of two outriggers were identified near one-third and two-thirds of the building height.

Bayati et al. (2008) [7] investigated multi-outrigger systems for improving the lateral stiffness of tall buildings. Their numerical study demonstrated that multiple outriggers connected through belt trusses effectively mobilize perimeter columns to resist overturning moments, thereby reducing bending moments in the central core and improving overall structural efficiency. The study confirmed that multi-outrigger systems perform significantly better than conventional braced-frame systems in very tall buildings.

Chang and Chen (2008) [8] studied the behaviour of two-outrigger systems in reinforced concrete tall buildings using compatibility-based analytical methods. A 60-storey building with a central core and perimeter columns was analysed under lateral loading. The study concluded that placing outriggers approximately at one-third and two-thirds of the building height minimizes roof displacement. However, the analytical model neglected the influence of floor slab stiffness, which may affect actual structural behaviour.

3. Methodology

3.1 Research Methodology

The present study evaluates the seismic performance of reinforced concrete tall buildings with different outrigger configurations using ETABS software. A three-dimensional analytical model of a high-rise RC building with a central shear wall core was developed in accordance with the provisions of IS 456:2000, IS 1893 (Part 1):2016, and IS 875 (Part 3):2015. Three structural models were considered: Model 1 with a bottom-level outrigger, Model 2 with bottom and mid-level outriggers, and Model 3 with bottom, mid-level, and top-level outriggers. This comparison was carried out to investigate the influence of the number and location of outriggers on the seismic behavior of the building.

The structural models were subjected to dead load, live load, wind load, and earthquake load according to the relevant Indian Standard codes. Linear elastic analysis was performed using Equivalent Static Analysis and Response Spectrum Analysis in ETABS. Identical material properties, geometric

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parameters, and loading conditions were maintained for all three models to ensure a consistent comparison.

The seismic performance of each model was assessed using key response parameters, including maximum lateral displacement, inter-storey drift, base shear, fundamental time period, and modal participation factors. The analytical results obtained from the three models were compared to determine the most efficient outrigger configuration in terms of lateral stiffness, drift control, and overall seismic performance. Based on these comparisons, the optimum outrigger arrangement was identified for improving the seismic behavior of reinforced concrete tall buildings.

3.2 Problem Statement

The rapid growth of high-rise construction has increased the demand for efficient structural systems capable of resisting lateral loads due to wind and earthquakes. Although outrigger systems are widely used to improve the stiffness and stability of tall buildings, the effectiveness of different outrigger configurations is not clearly established. Designers often face challenges in determining whether a single outrigger or multiple outriggers should be used and at which levels they should be placed to achieve maximum reduction in lateral displacement and inter-storey drift. Therefore, this study aims to compare the seismic performance of three practical outrigger configurations Bottom-Level Outrigger, Bottom + Mid-Level Outrigger, and Bottom + Mid + Top-Level Outrigger to identify the most efficient arrangement for enhancing the seismic performance of reinforced concrete tall buildings.

3.3 Structural Modeling

A three-dimensional reinforced concrete (RC) high-rise building was modelled using ETABS to evaluate the seismic performance of different outrigger configurations. The building consists of a central reinforced concrete shear wall core connected to perimeter columns through outrigger beams. Three analytical models were developed with identical geometry, material properties, and loading conditions, differing only in the number and location of outriggers: Model 1 with a bottom-level outrigger, Model 2 with bottom and mid-level outriggers, and Model 3 with bottom, mid-level, and top-level outriggers.

The building was designed using concrete grades ranging from M50 to M70 and Fe550 reinforcing steel, while the structural modelling and design followed the provisions of IS 456:2000, IS 1893 (Part 1):2016, IS 875 (Part 3):2015, and IS 800:2007. Maintaining identical modelling parameters for all three configurations ensured a reliable comparison of their structural response under seismic loading.

3.4 Outrigger Configurations

To investigate the influence of outrigger arrangement, three structural models were considered.

Model 1
1) Bottom-level outrigger only.

Model 2
2) Bottom-level outrigger.
3) Mid-height outrigger.

Model 3
1) Bottom-level outrigger.
2) Mid-height outrigger.
3) Top-level outrigger.

These configurations were selected to evaluate the effect of increasing the number of outriggers on the overall seismic performance of the building.

3.5 Material Properties

The structural properties adopted for modelling are summarized below.

Parameter	Value
Concrete Grade	M50–M70
Reinforcement Steel	Fe550
Confinement Steel	Fe250
Building Height	257.6 m
Typical Storey Height	3.9 m
Wall Thickness	450–1200mm
Slab Thickness	150–400 mm

These material properties were selected to represent a realistic reinforced concrete tall building suitable for high-rise construction.

3.6 Loading Criteria

The structural models were subjected to gravity, wind, and earthquake loads.

Dead Load
1) Self-weight of structural members
2) Superimposed dead load = 1.5 kN/m²

Live Load
1) 2–3 kN/m²

Wall Load
1) 8.3 kN/m

Parapet Load
1) 2.88 kN/m

Concrete density was taken as 25 kN/m³.

3.7 Seismic Parameters

Earthquake loading was assigned according to IS 1893 (Part 1):2016 using the following parameters:

Parameter	Value
Seismic Zone	Zone III
Zone Factor (Z)	0.16
Importance Factor (I)	1.2
Response Reduction Factor (R)	5
Soil Type	Type I
Mass Source	DL + SDL + 25% LL

3.8 Wind Parameters

The Wind loading was assigned according to IS 875 (Part 3):2015.

Parameter	Value
Basic Wind Speed	44 m/s
Terrain Category	3
Risk Coefficient (k_1)	1
Topography Factor (k_3)	1
Importance Factor (k_4)	1

3.9 Structural Analysis

The structural models were analysed using ETABS under linear elastic conditions. The following analysis procedures were adopted:
1) Equivalent Static Analysis
2) Response Spectrum Analysis

The same loading conditions and modelling assumptions were maintained for all three configurations to ensure a consistent comparison.

3.10 Performance Parameters

The seismic performance of each outrigger configuration was evaluated using important structural response parameters, including:
1) Maximum lateral displacement
2) Inter-storey drift
3) Base shear
4) Fundamental natural time period
5) Modal participation factors

These parameters were selected to assess the lateral stiffness, dynamic characteristics, and overall seismic behaviour of the building under different outrigger configurations.

3.11 Performance Parameters

The analytical results obtained from all three models were extracted and compared to identify the most efficient outrigger arrangement. Graphical and tabular comparisons of displacement, drift, modal characteristics, and base shear were used to evaluate the effectiveness of each configuration. The configuration exhibiting minimum lateral displacement and storey drift while maintaining favourable seismic response characteristics was identified as the optimum structural system.

4. Conclusion

The present study investigated the seismic performance of reinforced concrete (RC) tall buildings with different outrigger configurations using ETABS. Three structural models were developed with identical building geometry, material properties, and loading conditions, differing only in the number and location of outriggers. The configurations considered were: Model 1 with a bottom-level outrigger, Model 2 with bottom and mid-level outriggers, and Model 3 with bottom, mid-level, and top-level outriggers. The comparative analysis was carried out to evaluate the influence of multiple outriggers on the overall structural response under seismic loading.

The analytical results clearly indicate that the incorporation of outriggers significantly improves the lateral performance of tall buildings by increasing structural stiffness and reducing lateral deformations. Among the three models, the building with a single bottom-level outrigger showed the highest lateral displacement and comparatively larger inter-storey drift. Although this configuration enhanced the stiffness of the lower portion of the structure, its contribution to controlling the overall lateral response was limited. Consequently, a single outrigger system may not be sufficient for very tall buildings subjected to severe seismic and wind loads.

The introduction of a second outrigger at the mid-height of the building produced a noticeable improvement in structural performance. The additional outrigger enhanced the interaction between the central core and the perimeter columns, resulting in improved load transfer and greater resistance to overturning moments. As a result, the maximum roof displacement decreased, while inter-storey drift was reduced throughout the height of the building. The displacement profile also became more uniform, indicating better distribution of lateral forces and improved structural efficiency compared with the single-outrigger configuration.

From a practical design perspective, the results indicate that the strategic placement of outriggers is more important than simply increasing member sizes to improve structural performance. Multiple outriggers provide greater lateral stiffness without significantly increasing the dimensions of the central core or perimeter columns, thereby enabling more economical and efficient structural solutions. In addition, the use of outriggers at mechanical or refuge floors can minimize the impact on usable floor space while maintaining architectural flexibility.

Overall, the findings of this research confirm that outrigger systems are highly effective for enhancing the seismic performance of reinforced concrete tall buildings. Among the three configurations investigated, the Bottom + Mid + Top Outrigger System provides the optimum structural response by minimizing lateral displacement, controlling inter-storey drift, and improving overall lateral stiffness. Therefore, this configuration is recommended for the design of high-rise reinforced concrete buildings located in seismic regions, where structural safety, serviceability, and occupant comfort are primary design considerations.

References

[1] Abu Talha Anwar Pasha Deshmukh, Durgesh H. Tupe,2021, ‘Review Paper on Research Done in Effects of Outrigger Systems in High Rise Buildings in Siesmic Zones’, International Journal for Research in Applied Science & Engineering Technology, Volume 13 Issue 8.
[2] Sujith Reddy B, Dhanush S, 2025, ‘Study on response of outrigger structure to non- linear dynamic analysis’, International Journal of Creative Research Thoughts’, Volume 13 Issue 3.

[3] Hasan Raza Siddique, Hitesh Kodwani,2025, ‘Comparative Analysis of Different Outrigger System At Different Height and Belt-Truss Systems’, International Journal for Science and Advanced Research in Technology, Volume 11 Issue 8.
[4] Raj J Javiya,2024, ‘A Review on Different Types of Outriggers Structural System for High Rise Buildings’, International Journal for Scientific Research & Development, Volume 12 Issue 3.
[5] Arpita Marik, Arya Banerjee, 2023, ‘Analysis of effect of wind & seismic force on multistoried building with outrigger framing system’, International Research Journal of Engineering and Technology, Volume 10 Issue 9.
[6] Habrah, A, Batikha, M & Vasdravellis, 2022, 'An analytical optimization study on the core-outrigger system for efficient design of tall buildings under static lateral loads', Journal of Building Engineering, vol. 46, 103762. https://doi.org/10.1016/j.jobe.2021.103762.
[7] Sanjay k. hirani, Abbas Jamani, Aakash Suthar, 2021, Seismic Analysis of Outrigger and Flag-Wall System in High-Rise Structure with Regular and Irregular Plan. Student, Master in Structural Engineering’, L.J.I.E.T., Gujarat, India.
[8] Narendra Reddy, Anjana Devi, 2021, ‘The use of outrigger and belt truss system for high rise concrete buildings’, International Journal for Advanced Research in Science & technology, Volume 11 Issue 3.
[9] Nimish Pravinkumar Patrekar, Sachin B. Mulay, 2019, ‘Analysis of structure to locate the optimum position of outrigger and belt truss system in tall buildings’, International Journal of Technical Innovation in Modern Engineering & Science, Volume 5 Issue 6.
[10] Kim and Hong, 2019, ‘Influence of outrigger location and stiffness on the lateral and seismic performance of tall buildings using a series of three-dimensional numerical models’, International Journal of High Rise Buildings,Volume 5 Number 1.
[11] Kwang Ryang Chung, Wonil Sunu Structural Engineers, 2015, ‘Outrigger Systems for Tall Buildings in Korea’, International Journal of High Rise Buildings Volume 4 Number 3.
[12] D.H. Lee, E.S. Kim, D.E. Kang, T. Kim, 2012, Seismic Performance Evaluation of Twisted Outrigger System, Chang Minwoo Structural Consultants, Inc., Seoul, Korea.
[13] Chun-Chung Chen, King-Le Chang, Structural Engineers, 2008, ‘Outrigger System Study for Tall Building Structure with Central Core and Square Floor Plate’, CTBUH 2008 8th World Congress, Dubai.
[14] Z. Bayati, M. Mahdikhani and A. Rahaei, 2008, ‘Optimized use of Multi-Outriggers System to Stiffen Tall Buildings’, The 14th World Conference on Earthquake Engineering.
[15] Chang and Chen, 2004, ‘Behaviour and effectiveness of two–outrigger systems in tall buildings having a central reinforced concrete core and square floor plan’, International Journal of High Rise Buildings Volume 4 Number 8.