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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 increasing height of reinforced concrete (RC) buildings makes them more vulnerable to earthquake and wind-induced lateral forces. Outrigger systems are widely used to enhance the lateral stiffness and stability of tall buildings by connecting the central core to the perimeter columns. This study evaluates the seismic performance of a 257.6 m high RC residential building with three outrigger configurations: bottom-level, bottom and mid-level, and bottom–mid–top outriggers.**

The building was modelled in ETABS and analysed using the Equivalent Static Method and Response Spectrum Method in accordance with IS 456:2000, IS 1893 (Part 1):2016, IS 875 (Part 3):2015, and IS 800:2007. The performance of each configuration was assessed based on modal characteristics, modal participating mass ratio, base reactions, storey displacement, and inter-storey drift.

The results show that the addition of outriggers significantly improves the lateral stiffness and seismic performance of the building. Among the three configurations, the bottom–mid–top outrigger system provides the best overall performance, reducing the maximum top-storey displacement by approximately 32% compared with the single-outrigger configuration while maintaining storey drift within the permissible limits of IS 1893 (Part 1):2016. The study concludes that strategically placing multiple outriggers enhances the safety, stability, and serviceability of high-rise RC buildings under combined seismic and wind loading.

***Index Terms*—Outrigger system, Response spectrum analysis, Seismic performance, Storey displacement, Storey drift, Lateral stiffness.**

I. INTRODUCTION

Rapid urbanization, population growth, and the scarcity of available land have led to a significant increase in the construction of high-rise reinforced concrete (RC) buildings. As building height increases, the influence of lateral loads due to earthquakes and wind becomes more critical than gravity loads, making structural stability, occupant comfort, and serviceability major design considerations. Conventional lateral load-resisting systems become less efficient for very tall structures because of increased lateral displacement, inter-storey drift, and overturning moments. Consequently, advanced structural systems have been developed to enhance the lateral stiffness and overall performance of tall buildings.

Among these systems, the outrigger structural system has emerged as one of the most effective solutions for improving the lateral performance of high-rise buildings. An outrigger system consists of rigid horizontal elements, such as reinforced concrete walls, deep beams, or steel trusses, that connect the central core of the building to the exterior perimeter columns. Under lateral loading, the outriggers transfer forces from the core to the perimeter columns, allowing the entire structural system to act together in resisting overturning moments and lateral displacement. This interaction significantly increases the effective structural depth, enhances lateral stiffness, reduces storey drift, and improves the overall seismic and wind performance of the building.

In the present study, a high-rise reinforced concrete residential building with an overall height of 257.6 m was modelled and analysed using ETABS. Three different structural configurations were considered for comparison: (i) a bottom-level outrigger system, (ii) a bottom and mid-level outrigger system, and (iii) a bottom, mid, and top-level outrigger system. The analytical models were developed in accordance with the relevant Indian Standards, including IS 456:2000, IS 1893 (Part 1):2016, IS 875 (Part 3):2015, and IS 800:2007. Equivalent Static Analysis and Response Spectrum Analysis were performed to evaluate the behaviour of each structural configuration under gravity, wind, and earthquake loading.

II. 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.

III. OBJECTIVES

- To evaluate the seismic performance of reinforced concrete tall buildings with different outrigger configurations.
- To compare the influence of single, double, and triple outrigger systems on lateral displacement.
- To investigate the effect of outrigger configuration on inter-storey drift.

IV. 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 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.

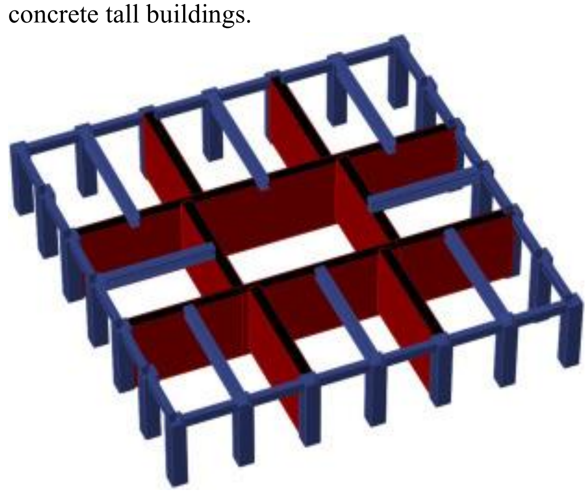

Figure1: Overview of Outrigger System

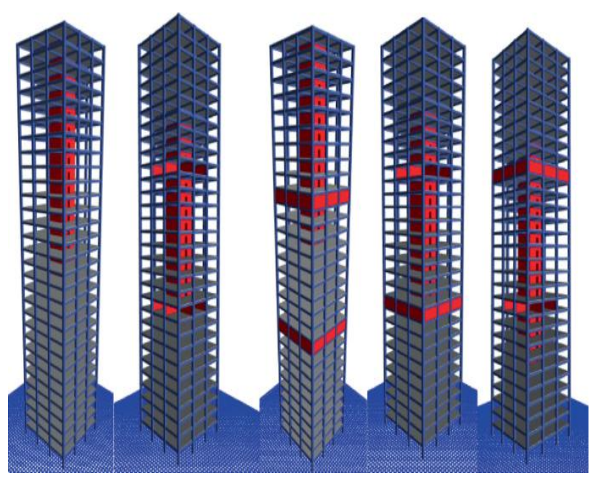

Figure 2:Outrigger Systems in Tall Building Stability

Building Geometry
▼
ETABS 3D Modelling
▼
Define Material Properties
▼
Apply Dead & Live Loads
▼
Define Response Spectrum (IS 1893:2016)
▼
Perform Dynamic Analysis
▼
Development of Three Analytical Models
▼
Extract Structural Responses
▼
Base Shear | Story Drift | Displacement
Time Period | Modal Participation
▼
Comparative Evaluation
▼
Conclusions

V. RESULT AND DISCUSSION

This study evaluated the seismic performance of a reinforced concrete high-rise building with three different outrigger configurations: Model 1 (Bottom-Level Outrigger), Model 2 (Bottom + Mid-Level Outriggers), and Model 3 (Bottom + Mid + Top-Level Outriggers). The analytical models were developed in ETABS and analysed under gravity, wind, and earthquake loading in accordance with the relevant Indian Standards. The structural performance was assessed using parameters such as modal characteristics, base reactions, storey displacement, and inter-storey drift. The results demonstrate that the provision of outriggers significantly improves the lateral performance of tall buildings by increasing structural stiffness and controlling lateral deformation. Although all three models satisfied the serviceability requirements, the efficiency of the structural system improved progressively as additional outriggers were introduced. The gravity load response and base reactions remained nearly identical for all three models, indicating that the change in outrigger configuration primarily influenced the lateral behaviour rather than the overall gravity load transfer. The comparison of modal characteristics showed only minor variations in natural periods and modal participation among the three models, confirming that all configurations provided adequate dynamic behaviour for seismic analysis. The cumulative modal mass participation exceeded the recommended limit, demonstrating that the adopted analytical models accurately represented the structural response. A significant improvement was observed in the storey displacement response. In the X-direction, the maximum top displacement reduced from approximately 255.84 mm in Model 1 to 198.00 mm in Model 2 and further to 173.84 mm in Model 3, indicating a substantial increase in lateral stiffness with additional outriggers. In the Y-direction, the displacement values were nearly similar for all three models, suggesting that the structural modifications had only a limited influence in that direction.

Modal Participation Comparison					
Single Outrigger Model		Double Outrigger Model		Triple Outrigger Model	
Mode	Period	Mode	Period	Mode	Period
1	8.624	1	8.462	1	8.501
2	7.469	2	6.614	2	6.463
2	5.813	3	5.602	3	5.595

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