

An Analytical Study of Monolithic High-Rise Building with Outrigger System

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Abstract: *In this study the lateral response of a G+50 reinforced-concrete high-rise building is examined for five central-core and outrigger configurations using ETABS Version 22. A 151.2 m building with a 65 m × 45 m plan is analysed using modal, equivalent-static, response-spectrum, wind and P-Delta procedures. The reference model has a central shear-wall/core without outriggers; the other models use virtual or conventional outriggers at H/2 or 3/4H together with a terrace-level outrigger. All models exceed 90% cumulative modal mass participation in both horizontal directions. The conventional system at H/2 gives the lowest fundamental period, whereas the conventional system at 3/4H gives the lowest maximum storey drift in all four reported load cases and the lowest terrace displacement in selected response directions. The results show that outrigger performance depends on the response parameter and loading direction, so no single measure should be used in isolation to select a configuration.*

Keywords: high-rise building; outrigger system; conventional outrigger; virtual outrigger; ETABS; lateral displacement; storey drift.

1. Introduction

The construction of high-rise buildings is increasing because of limited land availability and the need to accommodate more people and facilities within developed areas. With an increase in building height, the effect of lateral loads such as wind and earthquake forces becomes more important. Unlike gravity loads, lateral loads can produce considerable horizontal displacement, storey drift and overturning effects. Therefore, adequate stiffness and a suitable lateral load resisting system are necessary for the safe performance of a tall building.

In reinforced concrete high-rise buildings, a central shear wall or core is commonly used to resist lateral loads. However, for taller structures, the core alone may not provide sufficient control of lateral deformation. An outrigger system can be used to improve the interaction between the central core and the perimeter columns. It connects the core with the outer columns and makes better use of the axial stiffness of these columns. This can increase the effective lateral stiffness of the building and reduce its overall deformation.

The present study focuses on the behavior of a G+50 reinforced concrete building when different types and locations of outriggers are introduced. The main purpose is not only to study whether an outrigger improves the response, but also to compare virtual and conventional systems at two different heights. Keeping the basic building geometry and structural properties the same for all models makes it possible to observe the effect of the outrigger arrangement more clearly.

Previous studies reviewed in this work indicate that outrigger systems can improve the lateral performance of tall buildings. However, the amount of improvement depends on the type of outrigger, its vertical location, the building height

and the loading condition. Several studies have examined either the location of the outrigger or the difference between conventional and virtual systems. The present work combines these two aspects in one G+50 building model. The study therefore compares five configurations under the same basic structural conditions and evaluates their response using common structural parameters.

2. Literature Review

The studies considered in the literature review provide a general understanding of the behaviour of outrigger systems in tall buildings. Roy Shyam Sundar studied tall reinforced concrete structures subjected to seismic and wind loading and reported improved lateral performance with outriggers. Mulla studied an outrigger system with steel bracing and reported its effect on the lateral response of a tall reinforced concrete structure. Patel and Machhi compared tall RC buildings with shear walls and outriggers and found that combining the systems can provide better displacement control.

Raut and Dahake studied the effect of outrigger location and reported differences in displacement, drift, time period and story shear for different positions. Khan and Gore reviewed different aspects of outrigger systems and discussed the importance of selecting the outrigger position according to building height and loading conditions. Other studies included in the review considered conventional, virtual, offset and belt-truss arrangements.

From the reviewed work, it was observed that many studies are based on lower or medium-height buildings, or they study either outrigger location or outrigger type separately. There is scope for a direct comparison of both parameters in a taller G+50 reinforced concrete building while keeping the remaining structural properties unchanged. This forms the basis of the present study.

Volume 15 Issue 10, October 2026

Fully Refereed | Open Access | Double Blind Peer Reviewed Journal

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The literature also shows that the response of an outrigger system cannot be judged from a single parameter. A configuration that gives a lower time period may not necessarily give the lowest storey drift or displacement. Hence, the present study considers several response parameters together. The models are analysed for seismic and wind-related conditions, and their behaviour is compared in terms of dynamic characteristics and lateral deformation.

Based on the literature reviewed, the main gap considered in this work is the limited comparative study of outrigger type and vertical placement in a taller G+50 reinforced concrete building. To address this, five models are developed with the same building geometry and material properties, while only the outrigger arrangement is changed. This approach helps in identifying the effect of the outrigger type and location on the structural response.

3. Methodology

A three-dimensional reinforced concrete model of the G+50 building was developed in ETABS Version 22. The building has a regular rectangular plan of 65 m × 45 m with 5 m grid spacing. The first storey height is 4.2 m and the typical storey height is 3.0 m, giving a total structural height of 151.2 m. A central reinforced concrete shear wall/core is provided as the main lateral load resisting system. Lift and staircase areas are kept as slab openings in the model.

The basic dimensions and material properties were kept the same for all five models so that the effect of the outrigger system could be compared directly.

Table 1: Principal Parameters of the analytical model

Parameter	Adopted value
Building configuration	G+50 storey RC high-rise
Plan dimensions	65 m × 45 m
Grid spacing	5 m
First storey height	4.2 m
Typical storey height	3.0 m
Total structural height	151.2 m
Software	ETABS Version 22
Core/shear wall	Central; 350 mm thick; M40
Outrigger section	700 × 400 mm; M30

The concrete grades and member sizes were selected according to the structural requirements considered in the study. Beams are 300 × 550 mm and use M30 concrete with HYSD 500 reinforcement. Column sizes are reduced at higher storeys: 1200 × 1200 mm with M50 concrete from the ground to the 10th floor, 1000 × 1000 mm with M40 concrete from the 11th to 20th floor, 800 × 800 mm with M40 concrete from the 21st to 40th floor, and 750 × 750 mm with M40 concrete from the 41st floor to the terrace. The slab thickness is 175 mm and M40 concrete with HYSD 500 reinforcement is used.

The gravity loads considered in the model include dead load, live load, floor finish and wall loads. The adopted live load is 2.0 kN/m², floor finish load is 1.5 kN/m², external wall load is 13.8 kN/m and internal wall load is 9.0 kN/m. Seismic loading is defined according to IS 1893 (Part 1):

2016 for Zone III, with a zone factor of 0.16, importance factor of 1.2, response reduction factor of 5.0 and medium soil condition (Type II). Wind loading is considered according to IS 875 (Part 3): 2015 for Mumbai, with a basic wind speed of 44 m/s. The study objective is to compare the effect of outrigger type and location on dynamic characteristics and lateral deformation, rather than to infer performance from a single parameter.

Table 2: Building configurations compared in the study

Model	Configuration
M1	Central shear wall only; no outrigger
M2	Virtual outrigger at H/2 + terrace
M3	Virtual outrigger at ¾H + terrace
M4	Conventional outrigger at H/2 + terrace
M5	Conventional outrigger at ¾H + terrace

Modal analysis is carried out to obtain the natural periods and modal mass participation of the building. Equivalent static analysis and response spectrum analysis are used to study the seismic response. Wind load cases are also included to study the lateral behaviour of the building. P-Delta analysis is considered to account for the effect of gravity loads on the laterally displaced structure. The final comparison is made using fundamental time period, base shear, terrace displacement and maximum storey drift.

Before analysing the complete building, the modelling procedure was checked using a simply supported beam with an 8 m span and a 230 mm × 600 mm cross-section subjected to a uniformly distributed load of 20 kN/m. From manual calculation, the maximum bending moment is 160 kN-m and the maximum shear force is 80 kN. The corresponding ETABS results were reported to be approximately the same. This preliminary check provided confidence that the modelling and loading procedure used for the building analysis was appropriate.

4. Result & Discussion

The five ETABS models were compared to understand how the type and location of the outrigger affect the structural response of the G+50 building. Since the building geometry, material properties and main loading parameters were kept unchanged, the differences in the results can mainly be related to the outrigger arrangement. The discussion focuses on modal mass participation, fundamental time period, base shear, terrace displacement and maximum storey drift.

Modal Mass Participation

The cumulative modal mass participation after the first ten modes is more than 90% in both principal horizontal directions for all five models. The values range from 92.38% to 92.42% in the X direction and from 91.35% to 91.41% in the Y direction. These values satisfy the modal mass participation requirement considered in IS 1893 (Part 1): 2016. The difference between the five models is very small, which indicates that changing the outrigger arrangement does not significantly change the participating mass of the structure.

Table 3: Cumulative modal mass participation

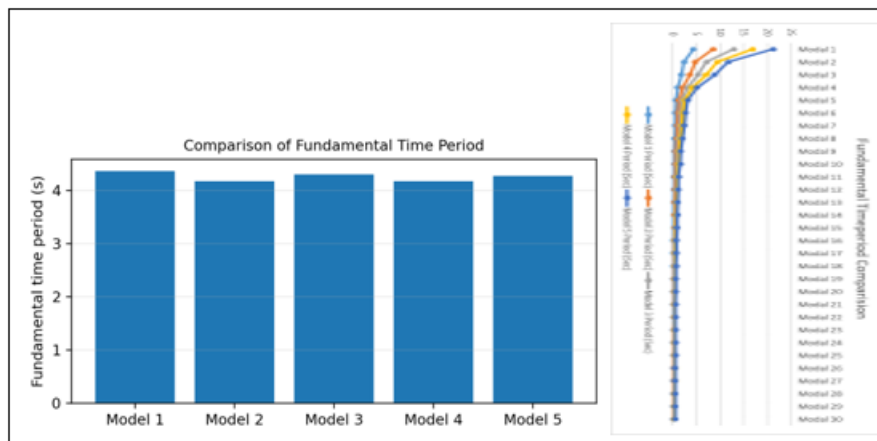
Model	Modes	UX cumulative	UY cumulative
M1	10	92.38%	91.35%
M2	10	92.40%	91.41%
M3	10	92.40%	91.38%
M4	10	92.40%	91.41%
M5	10	92.42%	91.39%

Fundamental Time Period

The reference model (M1) has a fundamental time period of 4.362 s. After introducing the outriggers, the time period reduces in all four modified models. M2 and M4, both having the outrigger at H/2, give the lowest period of 4.173 s, which is a reduction of 4.33% compared with M1. M3 gives a period of 4.301 s, while M5 gives 4.271 s. While the first mode period exceeds the approximate T_a limit,

examining the higher modes reveals critical behavior. From Mode 2 onwards, the periods fall well within the code limit. The first mode represents the global translational sway of the building. The outrigger system successfully restricts this global sway, reducing the period and significantly increasing the overall stiffness and rigidity of the structure to resist lateral forces.

The reduction in time period indicates that the modified structural systems have higher effective lateral stiffness than the reference model. The results also show that the position of the outrigger has an effect on the stiffness response. In this study, the H/2 configurations give the largest reduction in fundamental period, while the $\frac{3}{4}H$ conventional configuration performs better for the deformation-related parameters discussed later.

**Figure 1:** Comparison of fundamental time period

Base Shear

The equivalent static base shear shows only a small change between the five models. In the EQX case, the value increases from 14,431.33 kN for M1 to 14,546.24 kN for M5. The EQY values show the same numerical trend because the building configuration is regular. In response spectrum analysis, the RSX base shear varies from 9,610.29 to 9,734.38 kN, while RSY varies from 12,338.40 to 12,385.30 kN.

This indicates that while outriggers significantly enhance stiffness, they do not drastically alter the total horizontal seismic force the building experiences. The implementation of the IS 1893:2016 Clause 7.7.3 scaling factors (1.51 in X and 1.18 in Y) ensures that the dynamic forces are safely amplified to meet code minimums.

Table 4: Base shear from equivalent static and response spectrum analysis

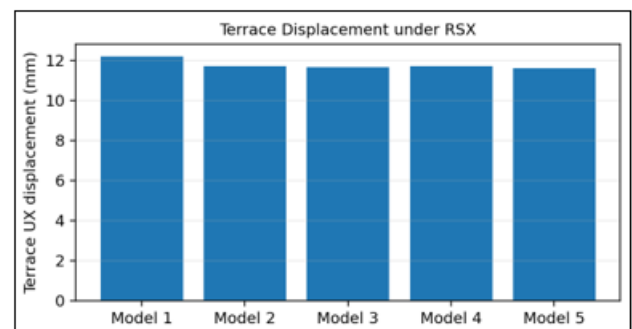
Model	EQX (kN)	EQY (kN)	RSX (kN)	RSY (kN)
M1	14431.33	14431.33	9670.68	12351.26
M2	14510.33	14510.33	9734.38	12385.30
M3	14509.88	14509.88	9610.29	12349.56
M4	14510.33	14510.33	9734.38	12385.30
M5	14546.24	14546.24	9621.50	12338.40

Terrace Displacement

For the reference model, the terrace displacement under RSX is 12.192 mm in UX and 17.603 mm in UY. After introducing the outrigger system, the displacement reduces

for the configurations considered. M5 gives the lowest UX displacement of 11.603 mm, which is about 4.83% lower than M1. For UY under RSX, M2 and M4 give the lowest value of 16.051 mm, corresponding to about 8.82% reduction from the reference model. Under RSY, M5 gives the lowest UY displacement of 16.224 mm, which is about 5.84% lower than M1.

The results indicate that the outrigger system helps in controlling the lateral movement of the upper part of the building. The improvement is not identical for all loading directions, which shows that both the structural configuration and the direction of lateral loading influence the response.

**Figure 2:** Terrace UX displacement under RSX.

Storey Drift

Comparing the performance, the Model 1 exhibited the highest drift demand. Among the retrofitted configurations, the conventional outrigger at 3/4H, Model 5 recorded the lowest drift values in both RSX and RSY directions. M5 has the lowest maximum drift in all four reported cases: 0.294% (EQX), 0.379% (EQY), 0.119% (RSX) and 0.125% (RSY). The EQX value falls from 0.431% in M1 to 0.294% in M5.

Table 5: Maximum storey drift for the five configurations

Model	EQX (%)	EQY (%)	RSX (%)	RSY (%)
M1	0.431	0.436	0.163	0.134
M2	0.335	0.406	0.128	0.132
M3	0.328	0.404	0.126	0.130
M4	0.335	0.406	0.128	0.132
M5	0.294	0.379	0.119	0.125

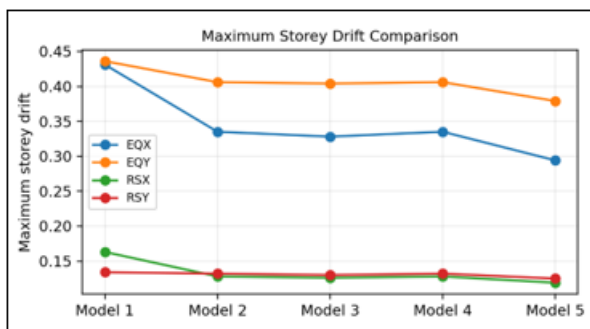


Figure 3: Comparison of maximum storey drift

The story drift in any storey shall not exceed 0.004 times the storey height under the design lateral seismic forces as per IS 1893 (Part 1): 2016 (Clause 7.11.1) Hence, Limit for Storey Drift is 12mm. All five models satisfied the IS 1893:2016 inter-storey drift limit of 12 mm.

5. Conclusion and Future Scope

This study evaluated the structural response of a G+50 reinforced concrete building by analyzing five key parameters modal mass participation, fundamental time period, base shear, roof displacement, and storey drift. The results demonstrated that modal mass and base shear remained relatively consistent across all configurations, indicating that outriggers primarily enhance stiffness rather than altering the overall seismic mass. However, the introduction of outriggers significantly reduced the fundamental time period, roof displacement, and storey drift compared to the baseline shear wall model. Furthermore, all configurations successfully satisfied the IS 1893 inter-storey drift limit, confirming the structural efficiency of outrigger systems under seismic loading.

Comparing the five models, the baseline configuration Model 1 exhibited the most flexible behavior, recording the highest time period, roof displacement, and storey drift. While the 0.5H configurations Models 2 and 4 were highly effective at reducing the initial time period, the conventional outrigger at the 3/4H level Model 5 proved to be the most balanced and reliable overall. Model 5 provided the most

consistent reduction in roof displacement across both principal directions and recorded the lowest inter-storey drift values under response spectrum analysis. Consequently, Model 5 Conventional Outrigger at 3/4H and Terrace Level is concluded to be the optimal configuration for controlling lateral deformation and enhancing the overall rigidity of the tall building.

Future research can build upon this study by incorporating non-linear time history analysis using real ground motions to evaluate performance under extreme seismic events. Additionally, further studies could explore the cost-effectiveness of steel or composite outriggers. The effect of irregular building plans, vertical irregularities and soil-structure interaction can also be investigated. Detailed member design, ductile detailing, Other systems such as offset outriggers, belt-truss systems, damped outriggers and multiple-outrigger arrangements can also be studied.

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