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Comparative Analysis of Tall Buildings with and without Outrigger System

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Abstract: The increasing demand for vertical construction in urban areas necessitates efficient structural systems to resist lateral loads such as wind and earthquakes. This study presents a comparative analysis of 22-storey regular and irregular buildings with and without outrigger systems, along with an optimised configuration aimed at reducing material consumption. Three models—conventional, outrigger, and optimised outrigger—are analysed using ETABS as per IS 1893:2016 and IS 875 provisions. Key performance parameters, including storey displacement, drift, base shear, and overturning moment, are evaluated. The results indicate that the outrigger system significantly enhances lateral stiffness, reducing displacement by up to 34% and drift by up to 10%. The optimised model achieves approximately 6% reduction in concrete volume while maintaining structural safety. The study highlights the effectiveness of outrigger systems in improving both structural performance and cost efficiency, particularly for irregular building configurations.

Keywords: Tall Buildings, Outrigger System, Seismic Analysis, Wind Analysis, Storey Drift, Storey Displacement, Structural Stability, Cost Optimisation

INTRODUCTION

Rapid urban growth and increasing population in countries like India have created a continuous demand for efficient use of limited land resources. As a result, vertical development in the form of tall buildings has become a common solution in metropolitan and developing urban areas. However, as the height of a structure increases, its behaviour is no longer governed only by gravity loads, but also significantly influenced by lateral loads such as wind and earthquake forces. These lateral forces induce storey displacement, inter-storey drift, and overturning moments, which directly affect the safety and serviceability of the structure.

To ensure structural stability, designers traditionally adopt a conventional approach by increasing the stiffness of structural elements such as columns and shear walls. Although this method improves resistance against lateral loads, it leads to higher material consumption and increased construction cost. Therefore, there is a need to adopt more efficient structural systems that can control lateral response without significantly increasing material consumption that can control lateral response without significantly increasing the size of structural members.

One such effective system is the outrigger system, which is widely used in tall buildings to enhance lateral stiffness. In this system, stiff horizontal elements such as beams or trusses connect the central core (shear wall system) to the exterior columns. This arrangement helps in reducing lateral displacement and overturning effects by mobilising the axial capacity of the outer columns, thereby improving overall structural performance.

In the present study, a comparative analysis is carried out on two types of 22-storey buildings, considering all relevant static and dynamic loads as per Indian Standards (IS Codes) and guidelines of the National Building Code (NBC) of India. Three different structural configurations are analysed for each building:

1. Conventional Model (Without Outrigger System):
In this model, stability is achieved by increasing the stiffness of columns and shear walls without using any additional lateral load-resisting system.

2. Model with Outrigger System:
Outriggers are provided at the 8th and 16th floors to control storey drift and displacement under lateral loading conditions.

3. Optimised Outrigger Model:
In this configuration, the outrigger system is combined with optimisation of column sizes to reduce material usage and overall construction cost, while maintaining adequate structural performance.

The objective of this study is to evaluate and compare the effectiveness of these systems in terms of lateral displacement, storey drift, and overall economy. The findings aim to provide a practical understanding of how the outrigger system can be utilised not only to improve structural stability but also to achieve cost-efficient design in tall buildings.

2) Review of Literature

The behaviour of tall buildings under lateral loads has been widely studied by researchers, especially with the increasing demand for high-rise structures in urban areas. Various structural systems such as shear walls, outriggers, belt trusses, and diagrid systems have been developed to improve stability and performance. This chapter presents a review of relevant studies related to lateral load resisting systems and their effectiveness.

One of the key parameters influencing the dynamic behaviour of a structure is its fundamental time period. A study by Kose [7] highlighted that the height of the building significantly affects the natural time period. It was also observed that the presence of shear walls and infill walls alters the stiffness of the structure, thereby influencing its dynamic response. The study indicates that increasing stiffness reduces the time period, which improves resistance to lateral loads.

The concept of distributed belt wall systems acting as virtual outriggers was studied by Eom et al. [6]. Their findings suggest that even when belt walls are not directly connected to the core, they can effectively reduce lateral drift. However, the performance depends on the number and positioning of these walls, making proper configuration an important design consideration.

Optimisation of outrigger systems has also been explored in previous studies. Kim et al. [8] investigated the relationship between outrigger stiffness and its optimal location. It was concluded that as the stiffness of the outrigger increases, its effective position shifts towards the lower levels of the building. This study emphasises the importance of proper placement of outriggers to achieve maximum efficiency in controlling displacement.

The effect of shear wall positioning has been studied by Akhil Ahamad and Pratap [9], where it was observed that buildings with shear walls placed symmetrically at corners perform better in terms of displacement and drift. The study also highlights that uniform stiffness distribution across the structure results in improved performance under seismic loads.

Further, Kushwaha and Mishra [10] reviewed different configurations of outrigger systems and concluded that increasing the number of outriggers enhances structural performance. Among various configurations, certain bracing arrangements, such as inverted V-type, were found to be more effective. However, the study also pointed out that shear walls still play a crucial role in resisting lateral loads.

A study by Singh et al. [11] compared different structural systems, such as diagrid and shear wall systems, under dynamic loading. The results showed that while the diagrid system increases base shear due to additional weight, it performs effectively in controlling displacement and storey drift, making it a viable alternative for tall buildings.

Recent experimental research by Ke et al. [12] focused on advanced shear wall configurations such as T-shaped composite walls. The study concluded that these walls provide better strength and deformation characteristics compared to conventional rectangular walls, especially under seismic loading conditions.

Similarly, Xu et al. [13] investigated the behaviour of composite core walls under cyclic loading. The results demonstrated good energy dissipation capacity and overall stability, indicating their suitability for high-rise structures. However, further studies were recommended for a better understanding of their behaviour under different loading conditions.

The base research paper by Hasrat et al. (2024) [16] carried out a comparative study of outrigger systems, core shear walls, and corner shear walls in a 40-storey building using response spectrum analysis. The study concluded that the outrigger system significantly reduces lateral displacement and storey drift compared to other systems. It also highlighted that outriggers improve the load transfer mechanism by engaging perimeter columns, thereby enhancing overall structural efficiency.

From the reviewed literature, it is evident that while conventional systems like shear walls are effective, advanced systems such as outriggers and their optimised configurations provide better control over lateral displacements and structural response. However, there is still a need to study their performance in combination with cost optimisation, which highlights the need for the present study to focus on both structural performance and cost optimisation.
This study presents a comparative analysis of tall buildings with and without an outrigger system under lateral loads. Three models were analysed: a conventional structure, a structure with outriggers at the 8th and 16th floors, and an optimised outrigger model with reduced column sizes. All analyses were carried out as per relevant IS codes and NBC provisions.

The results show that the conventional approach ensures stability but leads to higher material usage. The introduction of the outrigger system significantly reduces storey displacement and drift by increasing lateral stiffness and improving load distribution. The optimised model further demonstrates that column sizes can be reduced without compromising structural performance, resulting in better cost efficiency.

Overall, the outrigger system proves to be an effective solution for enhancing both structural stability and economy in tall buildings.

Despite extensive research on outrigger systems for improving lateral stiffness and reducing displacement in tall buildings, most studies primarily focus on structural performance parameters such as drift and base shear. Limited research is available that integrates structural performance with cost optimisation, particularly in the context of Indian construction practices and IS code provisions. Furthermore, the influence of optimised member sizing in conjunction with outrigger systems has not been sufficiently explored for different building configurations, such as regular and irregular plans. Therefore, the present study aims to bridge this gap by evaluating both structural efficiency and cost effectiveness through optimised outrigger configurations.

METHODS

Modelling Approach

In this study, two 22-storey buildings (C-shaped and regular residential) located in Pune, India, are modelled and analysed using ETABS software. Three different structural models are considered:

1. Model 1: Conventional Structure

A basic model without an outrigger system, where stability is achieved by increasing the stiffness of columns and shear walls.

2. Model 2: Structure with Outrigger System. Outriggers are provided at the 8th and 16th floors, connecting the core to outer columns to reduce displacement and storey drift.

3. Model 3: Optimised Outrigger Structure

The outrigger system is used along with reduced column sizes to optimise material usage and overall cost while maintaining structural safety.

All models are analysed for gravity and lateral loads as per IS 875, IS 1893:2016. The comparison is based on parameters such as storey displacement and storey drift.

Optimization Criteria

The optimisation of the structural system is carried out with the objective of minimising material consumption while ensuring structural safety. The objective function is defined as the reduction in concrete volume of structural elements. The constraints considered include:

Storey drift $\leq 0.004h$ (as per IS 1893:2016)

Lateral displacement $\leq H/500$

Structural safety under load combinations as per IS codes

The optimisation is achieved through iterative reduction of column sizes while monitoring the performance parameters to ensure compliance with permissible limits.

Design Parameters

Number of Storey: G +22

Typical Storey Height: 3.25 m

Dimension of Office Building: 40.5 x 84 m

Dimension of Residential Building: 26.4 x 13.4

Grade of Concrete: M45

Grade of Steel: Fe 550

Density of concrete: 25 kN/m^3

Wall Load: 15 kN/m^2

Live Load: 3 kN/m^2

Seismic Zone: III

Basic Wind Speed: 39 m/s

Seismic Load: Based on IS 1893:2016

Wind Load: Based on IS 875 Part III:2016

RCC Design: IS 456:2000

Analysis Tool: ETABS

Location of Building: Pune, India

Numerical Models

- Conventional Model Without Outrigger.

Conventional RCC Frame with Columns and Shear wall. No Outrigger system provided.

- Model With Outrigger.

RCC Frame Model with outriggers are provided at the 8th and 16th floors, connecting the central core to the perimeter columns.

- Optimised Model With Outrigger.

RCC Frame Model with outriggers are provided at the 8th and 16th floors, connecting the central core to the perimeter columns. Section sizes are reduced for optimisation.

Analysis Methodology

ETABS software is used for modelling and analysis of the structural stability of the building.

Response spectrum and the static equivalent method, as per IS 1893:2016, are utilised to study the dynamic behaviour of the structure.

Wind loads are assigned based on IS 875 Part III 2016 to study the structural performance in lateral directions.

Design Criteria

-Torsional Irregularity: The ratio of Max lateral displacement versus Min Lateral dimension in each principal Direction

-Storey Drift: Relative lateral displacement between two consecutive floors, a critical parameter for assessing the serviceability.

-Base Shear: Horizontal seismic force at the base of the structure.

-Overturning Moments: The moment causing the building to topple during seismic activity.

Result Comparison:

The performance of each model is compared based on:

-Maximum Lateral displacement in Seismic & Wind

-Storey Drift.

-Base Shear

-Overturning Moment

-Cost Comparison with respect to Concrete

The comparative evaluation is carried out to identify the most suitable lateral load-resisting system for high-rise RCC buildings subjected to seismic forces, with a focus on both structural safety and serviceability requirements.

Through the assessment of key performance parameters, the study helps in understanding how different structural systems influence the overall behaviour of tall buildings under lateral loading. This analysis provides practical insights that support better design decisions and the selection of efficient structural systems in high-rise construction.

Table 1. Details of the properties of the C-type building

Member	Model 1	Model 2	Model 3
Beam	300 x 600	300 x 600	300 x 600
Column	1000 x 1000	1000 x 1000	875 x 875
Slab	200	200	200
Shear wall	250	250	250
Brace	-	300 x 300	300 x 300

Table 2. Details of the properties of the Residential Building

Member	Model 1	Model 2	Model 3
Beam	300 x 600	300 x 600	300 x 600
Column	500 x 800	500 x 800	450 x 750
Slab	150	150	150
Shear wall	250	250	250
Brace	-	300 x 300	300 x 300

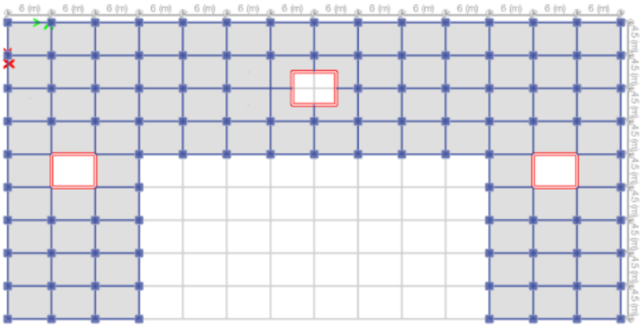

Figure 1: Plan of 22 Storey C-type building

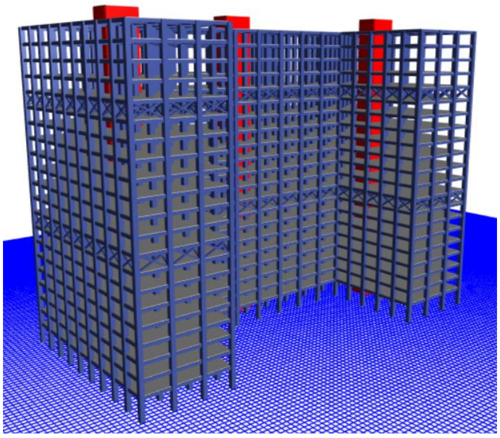

Figure 2: 3D Elevation of C-Type Building with outrigger

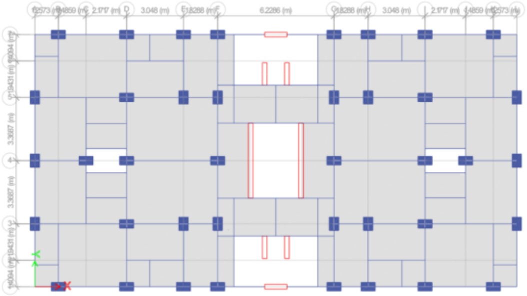

Figure 3: Plan of 22 Storey Residential Building

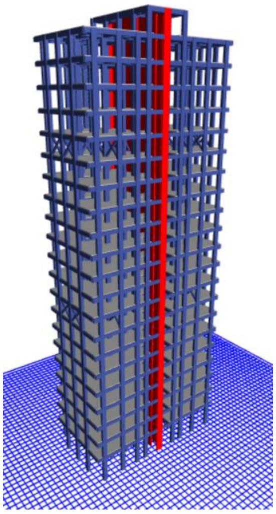

Figure 4: 3D Residential Building With Outrigger

RESULTS AND DISCUSSION

In this study, all six models (three for the C-shaped building and three for the residential building) are analysed using Response Spectrum Analysis and wind load cases in
S. The evaluation is carried out as per IS 456:2000, IS 1893, and NBC provisions. The permissible lateral displacement is taken as H/500, and the maximum storey drift is limited to 0.004h. All models are found to be within these limits, and the displacement ratio is also within the acceptable range.

Table 3 . Max Storey Displacement, Drift, Base Shear, Overturning Moment, Concrete Quantity in C Shape Building

Parameter	Model 1	Model 2	Model 3
Drift	0.000653	0.000603	0.000602
Displacement (mm)	36.094	24.113	24.380
Base Shear (kN)	9955	12562	11938
Overturning Moment	410456	403680	403970

(kNm)			
Concrete m^3	23257	23674	22083

Table 4 . Max Storey Displacement, Drift, Base Shear, Overturning Moment, Concrete Quantity in Residential Building

Parameter	Model 1	Model 2	Model 3
Drift	0.000756	0.000720	0.000724
Displacement (mm)	82.521	67.321	73.226
Base Shear (kN)	1830	2020	1947
Overturning Moment (kNm)	189561	188360	188760
Concrete m^3	3460	3486	3362

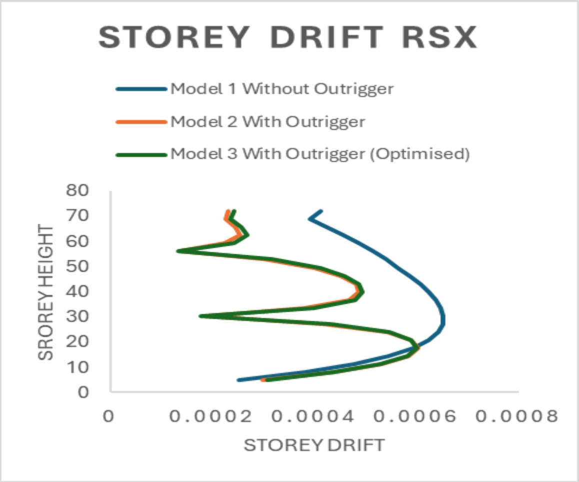

Figure 5: Storey Drift in the RSX case in C Shape Building

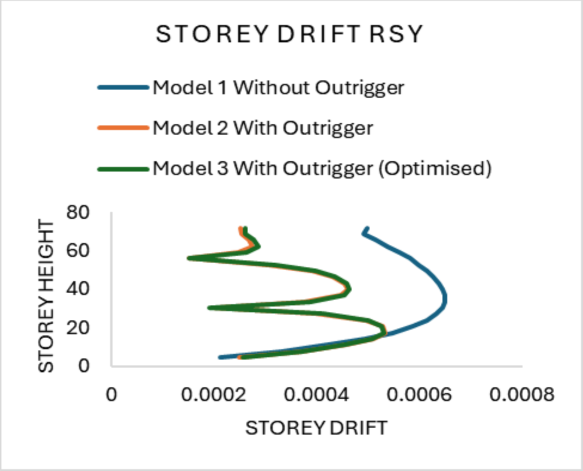

Figure 6: Storey Drift in RSY case in C Shape Building

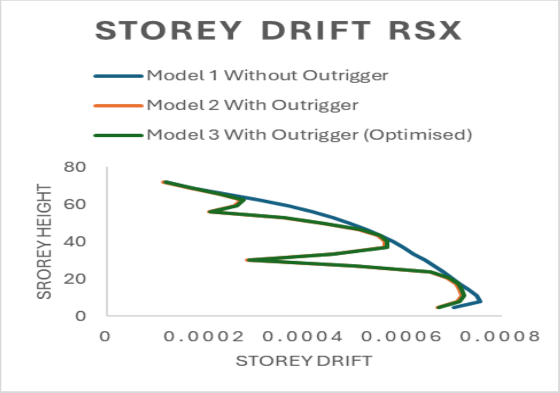

Figure 7: Storey Drift in the RSX case in Residential Building

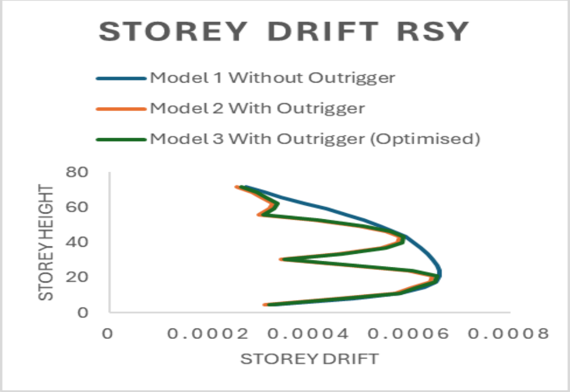

Figure 8: Storey Drift in the RSY case in the Residential Building

For the C-shaped building, the maximum storey drift in the conventional model is observed as 0.000653. With the provision of outriggers, the drift reduces by about 10%, and a further 2% reduction is achieved in the optimised model. In the residential building, the variation in drift is not very significant; however, an overall reduction of about 5% is observed with the outrigger system.

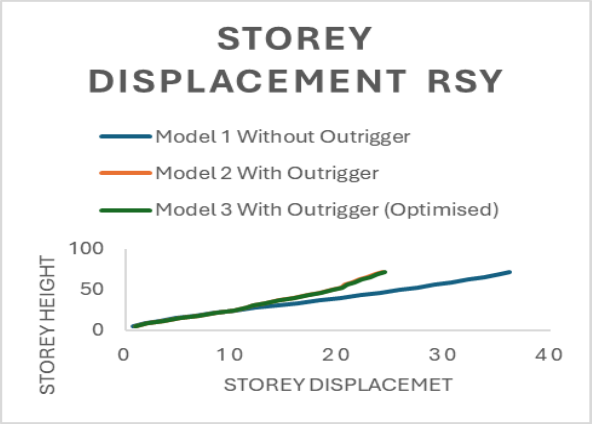

Figure 9: Maximum Displacement in C-Shaped Building

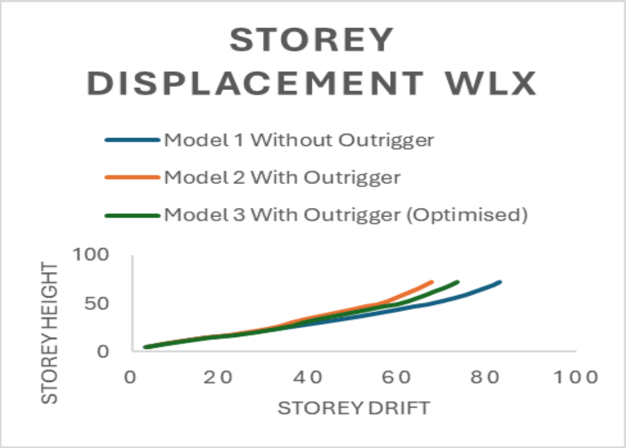

Figure 10: Maximum Displacement in Residential Building

The maximum lateral displacement in the C-shaped building is 36.096 mm under the response spectrum load case, which reduces to 24.38 mm with the outrigger system, showing a reduction of about 34%. In the residential building, the maximum displacement under wind load is 82.251 mm, which reduces to 73.226 mm, giving a reduction of approximately 11%. The reduction in displacement is more significant in the C-shaped building due to its irregular geometry, which is more sensitive to lateral loads. The outrigger system improves stiffness by engaging perimeter columns, thereby reducing lateral deformation effectively.

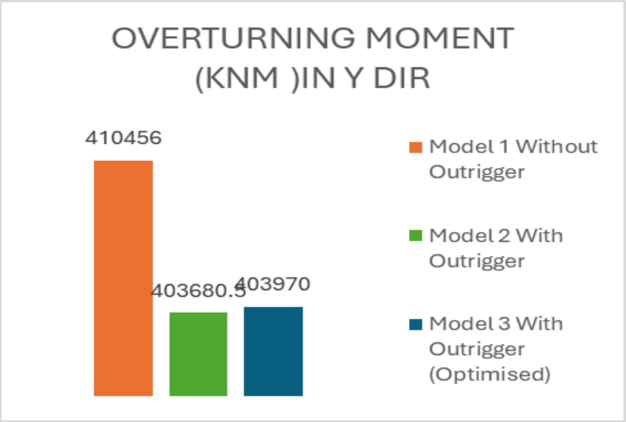

Figure 11: Overturning Moment in C Shape Building

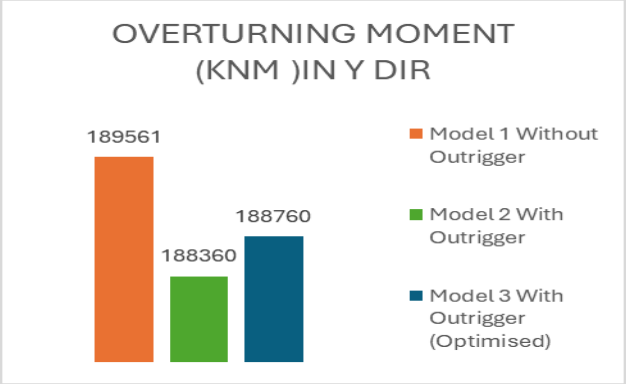

Figure 12: Overturning Moment in Residential Building

The overturning moment in the C-shaped building reduces from 410456 kNm to 403970 kNm, showing about 2% reduction. Similarly, in the residential building, it reduces from 189961 kNm to 188760 kNm, which is around 1.5% reduction. It is observed that the base shear increases in the outrigger model due to the increase in stiffness of the structure. Higher stiffness attracts more seismic forces, which results in increased base shear values.

In terms of material quantity, the concrete volume in the C-shaped building reduces from 23257 m³ to 22083 m³, resulting in about 6% savings, which corresponds to an approximate cost saving of ₹1 Crore. For the residential building, the concrete quantity reduces from 3461 m³ to 3362 m³, also showing about 6% reduction, with an estimated saving of ₹0.75 Crore.

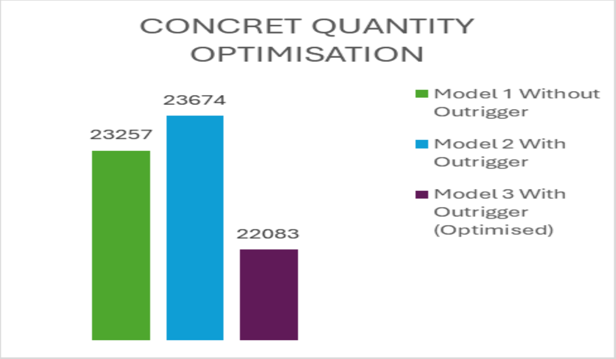

Figure 13: Concrete Quantity in C-Shaped Building

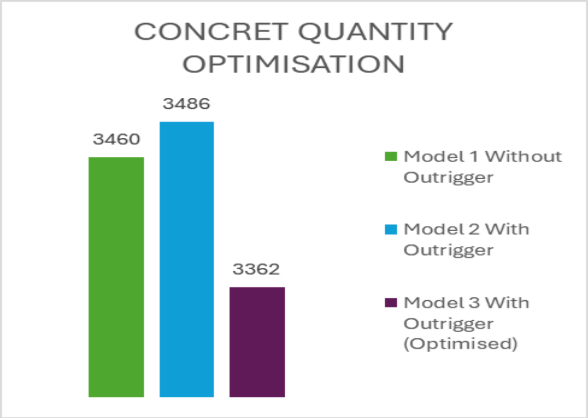

Figure 14: Concrete Quantity in Residential Building

The base shear values obtained from ETABS analysis are verified with approximate manual calculations based on IS 1893:2016 provisions. The results are found to be in reasonable agreement, confirming the accuracy of the analytical model. Additionally, the observed trend of increased base shear with increased stiffness is consistent with findings reported in previous literature.

Overall, the results indicate that the outrigger system improves structural performance by reducing displacement and drift, with more noticeable effects in irregular buildings. The optimised model further helps in reducing material consumption while maintaining structural safety. Comparative graphs for storey drift, displacement, overturning moment, and concrete quantity are used to support the analysis.

The dynamic characteristics of the structure, such as fundamental time period and mode shapes, play a significant role in determining the response under seismic loading. It is observed that the introduction of the outrigger system increases the overall stiffness of the structure, thereby reducing the fundamental time period. This reduction in time period leads to higher base shear but improved control over lateral displacements. The optimised model shows a balanced response, maintaining adequate stiffness while reducing material consumption.

CONCLUSION

The present study evaluates the performance of conventional and outrigger structural systems for tall buildings under seismic and wind loads. The results confirm that the outrigger system significantly improves lateral stiffness, leading to substantial reductions in storey displacement and drift. The effect is more pronounced in irregular configurations such as C-shaped buildings, where lateral instability is higher.

The optimised outrigger model demonstrates that material consumption can be reduced without compromising structural safety, achieving approximately 6% savings in concrete volume. However, the increase in base shear due to higher stiffness highlights the need for careful design considerations.

Overall, the study establishes that outrigger systems, when combined with optimisation techniques, provide an effective and economical solution for high-rise buildings. Future work may focus on nonlinear analysis, varying outrigger locations, and performance-based design approaches to further enhance the efficiency of such systems.

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