Comparative Analysis of RC Structure with and Without Outrigger Using Steel Bracing

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Abstract
The rapid expansion of tall building construction worldwide has presented new engineering challenges, particularly in ensuring the structural integrity of high-rise buildings under lateral loads. As building height increases, structural stiffness decreases, creating a need for efficient systems to mitigate risks from seismic and wind forces. This study explores the use of outrigger systems, specifically those incorporating steel bracing, to control excessive drift in reinforced concrete (RC) structures. A comparative analysis is performed on regular and irregular buildings with and without outrigger systems, utilizing centrally rigid shear walls and steel bracing as the primary structural components. Models are developed using ETABS software and analyzed using equivalent static and response spectrum methods. The study evaluates key structural performance indicators, such as lateral displacement, drift, storey shear, base shear, and the natural period, to assess the outrigger system's impact on stiffness and efficiency under static and dynamic loads. The results provide insights into minimizing structural and non-structural damage in high-rise buildings subjected to wind or seismic forces.

Key Words: Outrigger, Steel Bracing, RC Structures, Lateral Loads, Structural Performance, Seismic Analysis.

1. INTRODUCTION

The development of tall structures has advanced significantly due to urbanization and the demand for space-efficient solutions. High-rise buildings are now widely used for residential, office, and commercial purposes. However, the design of tall buildings in seismic-prone regions presents unique challenges, particularly due to lateral forces from wind and earthquakes. A substantial part of India is exposed to high seismic risk, requiring careful design considerations to address these lateral loads (1).

Historically, building designs focused primarily on gravity loads, but modern structural systems must account for lateral forces due to the increased slenderness of buildings (2). The structural systems used in high-rise buildings include rigid frames, braced frames, shear walls, and outrigger systems, each of which offers varying degrees of resistance to lateral loads (3, 4). Among these, the outrigger system has emerged as one of the most effective methods for controlling excessive drift and minimizing damage caused by lateral forces (5).

The outrigger and belt truss system connects the central core of a building to its external columns through stiff outriggers, effectively reducing lateral deflections (6). This system is particularly beneficial in high-rise buildings exposed to seismic or wind forces, as it helps limit the risk of structural and non-structural damage (7, 8). The outrigger system can be categorized into two main types: conventional outriggers& virtual outriggers. The conventional outrigger system connects the core directly to external columns, while the virtual system uses floor diaphragms to transfer forces indirectly (9).

This study compares the seismic performance of reinforced concrete (RC) buildings with and without outrigger systems using steel bracing. A 30-storey building is analysed under lateral loads using ETABS software, employing both equivalent static and response spectrum methods. The study evaluates key parameters such as lateral displacement, base shear, and drift to assess the structural performance (10). The addition of outriggers significantly enhances lateral stiffness, making it a viable solution for tall buildings in seismic zones (11).

2. OBJECTIVES OF THE WORK

a) To model and analyse high-rise structures to identify the most effective systems for resisting lateral loads.
b) To evaluate the performance of outrigger systems in regular and vertically irregular structures subjected to seismic forces.

c) To conduct a comparative analysis of buildings with and without outrigger systems.
d) To examine the behaviour of steel bracing outrigger systems in reinforced concrete (RC) tall structures.
e) To compare the effectiveness of outrigger systems using both Equivalent Static Method and Dynamic Analysis (Response Spectrum Method) as per IS 1893:2002 guidelines.
f) To study key structural parameters, including storey shear, displacement, storey drift, storey stiffness, fundamental natural time period, and base shear.

3. SCOPE OF THE WORK

Structural Modelling: Model and analyse high-rise RC structures using ETABS, with and without outrigger systems.
Seismic Analysis: Evaluate structures under seismic loads using Equivalent Static and Response Spectrum methods as per IS 1893:2002.
Comparative Study: Compare performance of buildings with and without outriggers, focusing on lateral stiffness and displacement.
Steel Bracing Outriggers: Assess the impact of steel bracing outriggers on seismic performance.
Parameter Evaluation: Analyse key parameters such as storey shear, displacement, drift, storey stiffness, and base shear.

4. THEORY AND METHODOLOGY

Structure Specification: Analyse a 30-storey RC building with a total height of 90 meters, where each floor is 3 meters high. The building features a square plan with a central core.
Structural Model: Use a regular RC concrete moment-resisting frame as the base model. For comparison, incorporate an outrigger system with steel bracing and evaluate different geometric configurations.
Consistent Floor Height: Maintain a uniform floor height across all levels to ensure accurate and comparable results.
Outrigger Implementation: Integrate steel bracing as the outrigger system into the model and compare its performance with the base model.
Lateral Load Analysis: Apply lateral loads in accordance with IS 1893:2002 standards to evaluate structural behaviour under seismic conditions.
Result Analysis: Assess the impact of earthquake loads on the structure and draw conclusions based on the response of the building to these loads.

Model Data:
Structure Type: SMRF (Special Moment Resisting Frame)
Number of Stories: G+30
Storey Height: 3.0 meters
Plan Dimensions: 2704 m^2
Concrete Grade: M30 and M25
Steel Grade: Fe500
Slab Thickness: 150 mm
Beam Size: 550x300 mm and 450x300 mm
Column Sizes: 1000x1000 mm and 900x900 mm
Outrigger: Steel Bracing ISA 150x150x15 mm
Shear Wall Thickness: 0.3 meters
Soil Type: Medium soil
Lateral Load Analysis:

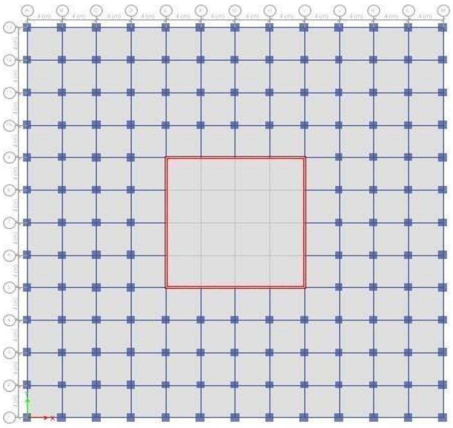

Fig-1: Plan view of square model

The study aims to assess the stability, serviceability, and performance of tall structures under lateral loads. It involves:

1.Structural Framework Evaluation: Investigate the structural frameworks of tall buildings, with a focus on outrigger systems in various geometric designs.

2.Seismic and Wind Assessment: Use static and dynamic methods, including time history analysis, to evaluate the building's response to seismic and wind loads. Key metrics include storey displacement, drift, shear, and mode shapes.

3. Seismic Force Analysis: Examine the effects of seismic forces, including P-waves, longitudinal waves, and S-waves, on building stability and displacement. Assess how different configurations of outriggers affect the building's performance.

Design Lateral Forces:

According to IS 1893, seismic forces typically have a more significant impact on structures than wind forces. Seismic activity generates complex ground vibrations in three-dimensional directions, requiring comprehensive analysis to ensure building safety and stability.

4.1 Load Combinations

For Gravity Analysis, the applied load combination is 1.5(DL + LL) [12]. In Equivalent Static Analysis, the combinations include 1.5(DL ± EQX), 1.5(DL ± EQY), 1.2(DL + LL ± EQX), 1.2(DL + LL ± EQY), and 0.9DL ± 1.5EQX/EQY [13]. For Wind Load Patterns, the combinations are 1.5(DL ± WLX), 1.5(DL ± WLY), 1.2(DL + LL ± WLX), and 1.2(DL + LL ± WLY) [14].

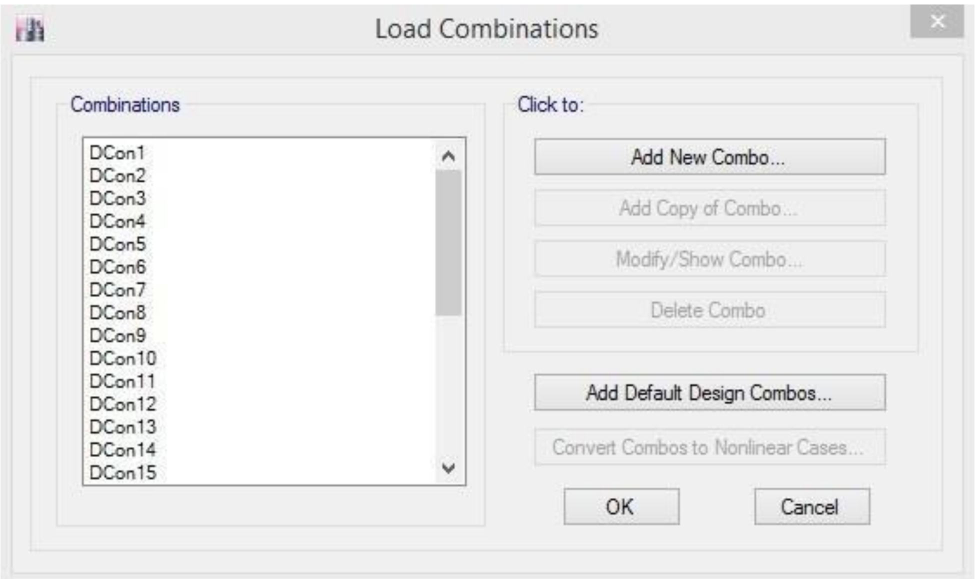

Fig-2: load combination

4.2 Introduction to software

ETABS 2015 is a specialized software program designed specifically for structural engineering applications. It facilitates both linear and nonlinear static and dynamic analysis, leveraging modern PC capabilities to handle complex, composite models efficiently [15]. The software integrates modelling, analysis, design, and optimization within a single user-friendly interface, fully compatible with Microsoft Windows [15, 16]. ETABS also enhances the visualization of results through advanced graphical presentations, making it easier for engineers to interpret and refine their models [17].

5. RESULTS AND DISCUSSIONS

The results are presented in tabular form. Systematic parameters such as storey lateral displacement, storey drift, storey stiffness, storey shear, and base shear are examined using the equivalent static method. The results for all models are compared, and the most suitable model is selected based on this comparison.

Storey Displacement:
The lateral displacements for the G+30 storey building model in square shape, for both without and with outrigger walls in X direction, have been calculated using the equivalent static method (EQS). These values are listed in the following table.

Table 1: Storey Displacement and Storey Drift of Square Model in Zone-IV for EQX

Storey	Storey displacement without outrigger (mm)	Storey displacement with outrigger (mm)	Storey	Storey drift without outrigger (m)	Storey drift with outrigger (m)
Storey 30	44.7	33.3	Storey 30	0.00039	0.00027
Storey 29	43.5	32.5	Storey 29	0.00042	0.00029
Storey 28	42.3	31.6	Storey28	0.00044	0.00031
Storey 27	40.9	30.7	Storey 27	0.00047	0.00033
Storey 26	39.5	29.7	Storey 26	0.00049	0.00034
Storey 25	38.1	28.7	Storey25	0.00050	0.00036
Storey 24	36.6	27.6	Storey24	0.00052	0.00038
Storey 23	35.0	26.4	Storey23	0.00053	0.00039
Storey 22	33.4	25.3	Storey 22	0.00052	0.00041
Storey 21	31.8	24.1	Storey21	0.00048	0.00042
Storey 20	30.4	22.8	Storey 20	0.00055	0.00043
Storey 19	28.7	21.5	Storey 19	0.00058	0.00044
Storey 18	27.0	20.2	Storey 18	0.00060	0.00044
Storey 17	25.2	18.9	Storey 17	0.00061	0.00045
Storey 16	23.4	17.5	Storey 16	0.00061	0.00045
Storey 15	21.6	16.2	Storey15	0.00061	0.00045
Storey 14	19.7	14.8	Storey 14	0.00060	0.00045
Storey 13	17.9	13.5	Storey 13	0.00059	0.00045
Storey 12	16.1	12.1	Storey 12	0.00056	0.00044
Storey 11	14.5	10.8	Storey 11	0.00049	0.00043
Storey 10	13.0	9.5	Storey 10	0.00053	0.00042
Storey 9	11.4	8.3	Storey9	0.00054	0.00041
Storey 8	9.8	7.0	Storey8	0.00052	0.00039
Storey 7	8.2	5.8	Storey7	0.00050	0.00038
Storey 6	6.7	4.7	Storey6	0.00047	0.00035
Storey 5	5.3	3.7	Storey5	0.00044	0.00033
Storey 4	4.0	2.7	Storey4	0.00040	0.00030
Storey 3	2.8	1.8	Storey3	0.00036	0.00026

Storey 2	1.7	1.0	Storey2	0.00031	0.00022
Storey 1	0.8	0.4	Storey1	0.00028	0.00013
Base	0.0	0.0	Base	0	0

The use of outrigger systems in tall buildings has been demonstrated to significantly enhance the structural performance by effectively reducing both lateral displacement and storey drift. The current study reveals that the incorporation of outriggers leads to a substantial decrease in displacement values across different storeys. Specifically, with the inclusion of outriggers, displacement measurements are reduced from 44.7 mm to 33.3mm at the top storey and 0.8mm to 0.4 mm at storey 1 [18][19]. This notable reduction in displacement indicates that outriggers play a crucial role in improving the building's ability to resist lateral forces, thus enhancing its overall stability.

Additionally, the storey drift values are significantly lowered in buildings equipped with outriggers. For instance, at Storey 30, the drift reduction is approximately 30% with the use of outriggers [20][21]. This decrease in drift is a critical factor in maintaining the structural integrity and serviceability of high-rise buildings under lateral loads. The observed performance improvements are consistent with findings from prior research, which underscores the importance of outrigger systems in bolstering lateral stiffness and controlling structural movement. These systems are instrumental in mitigating the adverse effects of lateral forces, thereby contributing to the enhanced resilience and stability of tall structures [22].

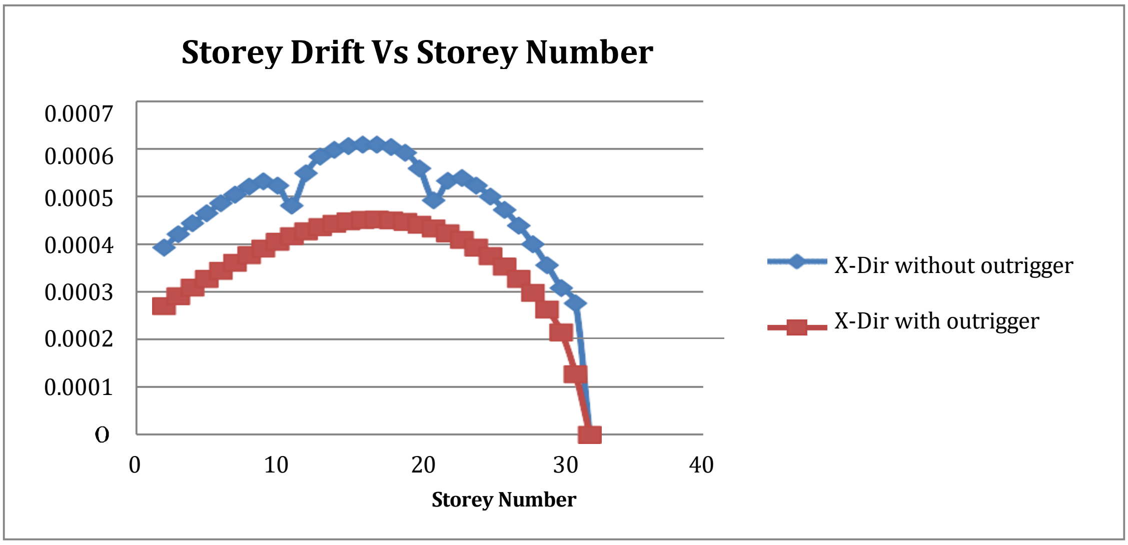

Chart-1: Storey Drift vs Storey Number for Square Model (EQX) in Zone-IV

6. CONCLUSION:

The study highlights that displacement in structures is heavily influenced by their geometry, and all results obtained conform to code limitations. The addition of outriggers significantly enhances the structure's performance under lateral loads by increasing flexural stiffness and reducing base shear in both static and dynamic scenarios. As the size of outriggers increases, displacement in tall structures decreases, while shear walls provided at the core further reduce internal forces. Additionally, the placement of outriggers at 1/3rd of the total height leads to greater displacement reduction in the upper storeys. The study also notes that structural behaviour under seismic loads varies across different designs, and outriggers are employed in various seismic zones based on regional requirements.

Furthermore, the use of X-steel bracing as outriggers in tall structures proves to be effective in minimizing lateral loads and storey drift. Symmetrical and asymmetrical floor designs contribute to reducing the self-weight of the structure. This study compares the behaviour of buildings with and without outriggers, demonstrating the clear benefits of incorporating outriggers in tall structures for improved stability and performance under lateral and seismic loads.

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