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# Analysis of RCC Framed 45 Storey Building Using Different Combination of Outriggers

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**Abstract***: In this modern age of civil engineering, the construction industry has embraced a notable inclination towards erecting towering structures, with skyscrapers emerging as integral components of urban development. This trend presents a multifaceted challenge, not only for architects but also for structural engineers, who must ensure these high-rise edifices possess a robust design foundation capable of withstanding diverse loads and their combinations. While both wind and seismic forces exert significant pressures on tall buildings, the former often takes precedence due to its higher magnitude and frequency. Consequently, the structural design of high-rise buildings necessitates careful consideration of gravity, wind, and seismic loads.*

*This study delves into the behaviour of reinforced concrete (RC) framed high-rise buildings (comprising 45 stories) augmented with outrigger truss systems constructed from both concrete and steel bracings. By exploring various configurations of outrigger placement, the aim is to mitigate structural deflection and compare the efficacy against conventional RC systems, both with and without shear walls.*

**Keywords:** High-rise building, Outriggers, bracing, displacement &storey drift, Earthquake & Wind forces

## I. INTRODUCTION

Various structural systems have been devised to mitigate lateral deflection and drift in high-rise constructions. Designers select a suitable system based on site conditions and the magnitude of imposed loads, aiming to enhance bending stiffness against seismic activity and strong winds. Additionally, the appropriateness of a structural system is influenced by the building's shape, elevation, and intended function. An effective structural system not only ensures stability but also minimizes displacement, drift, acceleration, shear force, and bending moment within the structure. Figure 1 illustrates several of these systems.

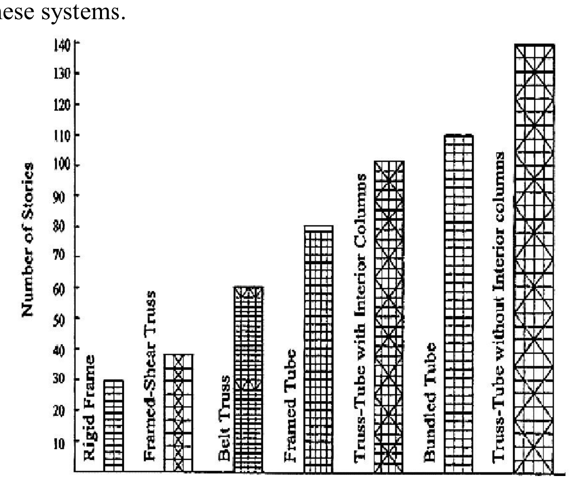


Fig. 1. Structural systems that resist lateral loads in tall buildings

The intensity of lateral load exertion escalates exponentially in correlation with the height of a building. Structures with lightweight frameworks can experience unsettling horizontal displacements for occupants, even in relatively mild seismic events. However, the implementation of an outrigger truss system offers a significantly sturdier structural

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framework adept at withstanding high-magnitude earthquakes. This system effectively mitigates structural deflections induced by seismic vibrations, thereby enhancing the overall stability and safety of the building.
The utilization of a core as a structural system proves highly effective and efficient in minimizing drift caused by lateral loads. Nonetheless, as the height of the building increases, relying solely on the core's stiffness becomes insufficient in restraining structural displacements to acceptable limits.While outriggers are recognized for their deep and sturdy design, they function as strong beams that establish a crucial link between the central core and the outermost columns. This connection is instrumental in preserving the columns' stability and efficiently mitigating swaying motions within the structure.
The restraint exerted by the outrigger system effectively reduces lateral displacement at each floor level. This phenomenon is illustrated in Figure 2. The outrigger truss system serves as a method of lateral load resistance, wherein external columns are interconnected to the central core wall via rigid outriggers and, if desired for architectural finesse, belt trusses at various levels. When lateral forces act upon the structure, the bending of the core initiates rotation in the stiff outrigger arms, which are linked to the central core, resulting in tension and compression forces within the columns. Additionally, the belt truss connects the peripheral columns to the outriggers, effectively anchoring them to the central core. This configuration restrains the core wall from undergoing unrestricted rotation, as depicted in Figure 3.

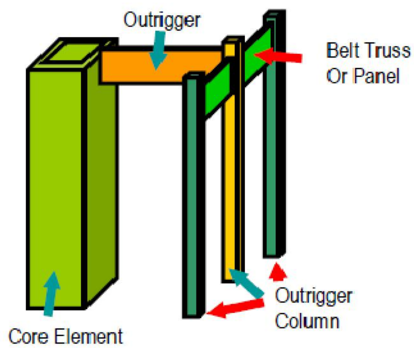

Fig. 2. Outrigger Truss System for resisting lateral loads

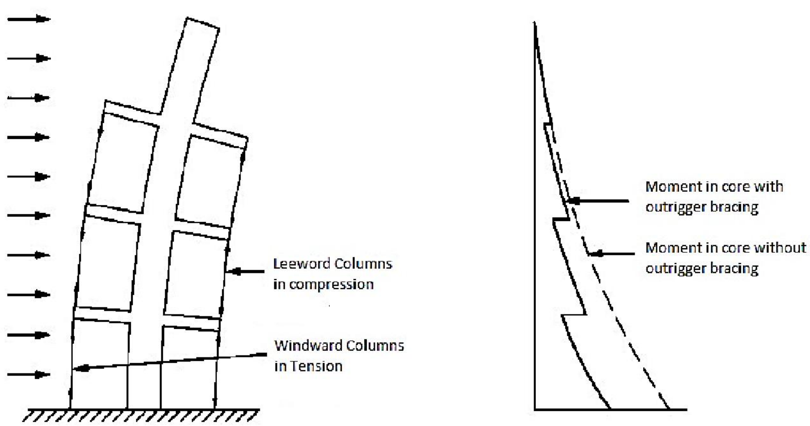

Fig. 3. Variations in bending moments induced by the Outrigger Truss System

## II. TEST SPECIMEN

### 2.1 Description of the Model

**A. Building structure:**

- This study focuses on a symmetrical reinforced concrete (RC) framed building spanning from ground level to the 45th floor. Various structural models were created and analysed using ETABS software accordingly.
- Different grid configurations with a consistent floor height of 3.0 m were utilized.

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A. 6 × 6 m with a total span of 18 m in each direction
B. 8 × 8 m with a total span of 24 m in each direction

- Connections – Rigid connections are established between the core and foundation, as well as between the structure and Concrete Outrigger beams, while pinned connections are utilized between the structure and Steel Outrigger beams.
- Location – Location of the building is assumed to be in Pune region.

**B. Structural Member Size**

**RCC member of M30**

- Column Size –300 × 400 mm
- Beam Size – 300 × 300 mm
- Lift Core Thickness – 300 mm
- Slab thickness – 180 mm

**Outrigger**

- Concrete – 300 × 400 mm
- Steel – ISMB 400 of Fe 345 (Properties sourced from SP 6)

**2.2 Loading**

- Dead Load –Calculated by multiplying cross-sectional area and density of concrete.
- Live Load – 2.5 kN/$m^2$
- Wind Load – Referring to the IS 875 (part 3): 1987 following factors are calculated;
  $k_1$ value – Derived from Table no. 1 for a basic wind speed of 39 m/s in Pune region, considering a general building with a 50-year lifespan.
  $k_2$ value – Assumed as 1.0 due to upwind slope greater than about 3°.
  $k_3$ value – Not required for calculation in ETABS.
- Earthquake Load – Referring to the IS 875 (part 3): 1987 following factors are calculated.
  Z (Zone Factor) – Pune region categorized under earthquake zone III, Z = 0.16.
  I (Importance Factor) – Commercial complex classified under other category buildings, I = 1.0.
  R (Response Reduction Factor) – Considering SMRF system, R = 5.0.
  Various load combinations are applied according to the default settings provided in ETABS.

## III. TEST PROGRAM

**3.1 Forming a model**

Various structural configurations of a reinforced concrete (RC) framed building consisting of ground plus 45 floors, with and without an outrigger truss system, have been created using ETABS software. A total of three structural models were developed for both concrete and steel outriggers, and each model was analysed in the ETABS software.

- RC framed building –Conventional
- RC framed building with Shear Wall at middle grid – Shear Wall
- RC framed building with outrigger at every 3$^{rd}$ floor (Concrete)– 3OC
- RC framed building with outrigger at every 4$^{th}$ floor (Concrete) – 4OC
- RC framed building with outrigger at every 5$^{th}$ floor (Concrete)– 5OC
- RC framed building with outrigger at every 3$^{rd}$ floor (Steel) – 3OS
- RC framed building with outrigger at every 4$^{th}$ floor (Steel) – 4OS
- RC framed building with outrigger at every 5$^{th}$ floor (Steel) – 5OS

All the above-mentioned models are prepared for 6 × 6 m&8 × 8 m

Various configurations of a reinforced concrete framed building, consisting of a ground floor and 45 upper floors, are examined using ETABS software. The analysis considers different placements of outrigger trusses for different grid sizes, and the outcomes are assessed based on the following criteria:

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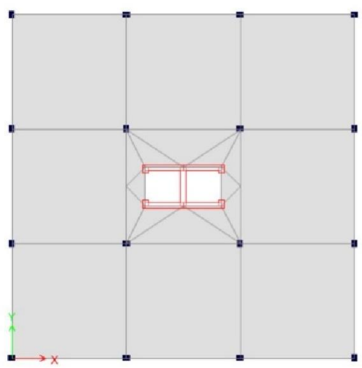
**3.2 Story Displacements**

Inter-story Drift.



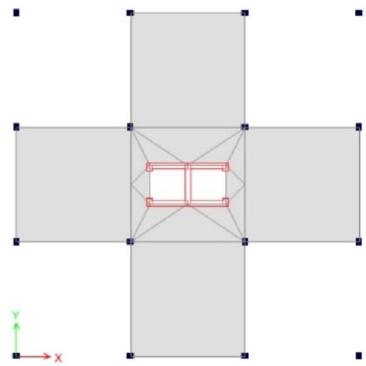
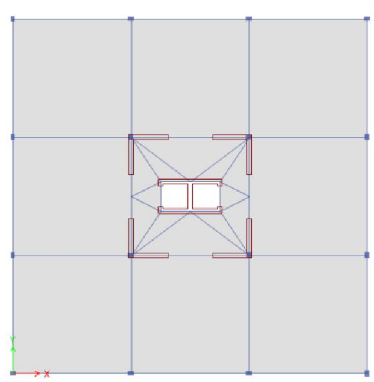


Fig. 4 (a). Plan view of Convention Model (Odd Floors) Fig. 4 (a). Plan view of Convention Model (Even Floors)



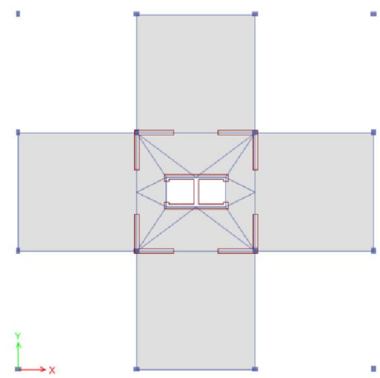
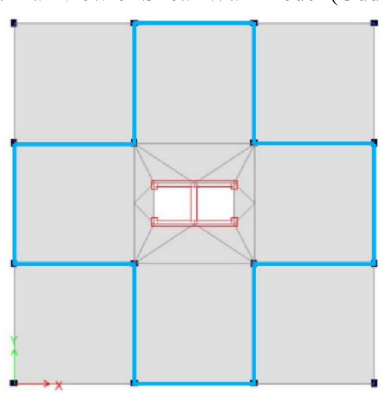


Fig. 5 (a). Plan view of Shear Wall Model (Odd Floors) Fig. 5 (b). Plan view of Shear Wall Model (Even Floors)



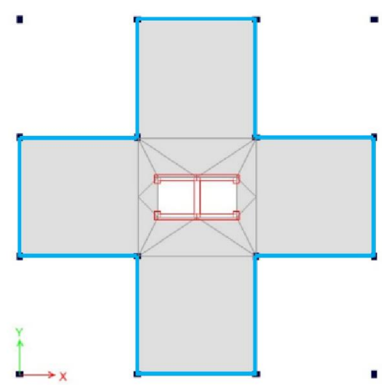


Fig. 6 (a). Plan view Model with Outrigger (Odd Floors) Fig. 6 (b). Plan view of Model with Outrigger (Even Floors)

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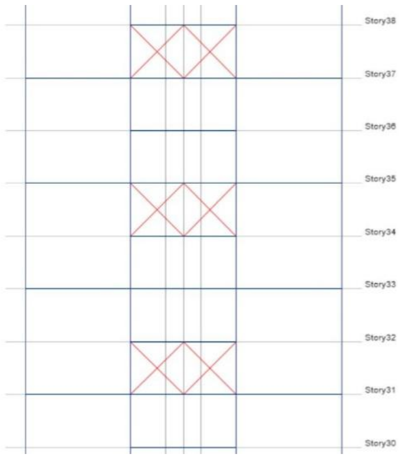


Fig. 7 (a). Elevation view with Outriggers at every 3rd Floor (Peripheral beams)

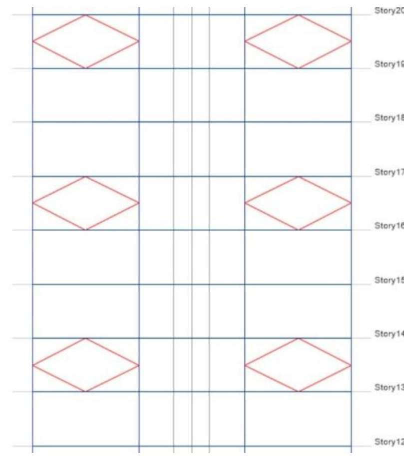


Fig. 7 (b). Elevation view with Outriggers at every 3$^{rd}$ Floor (Intermediate beams)

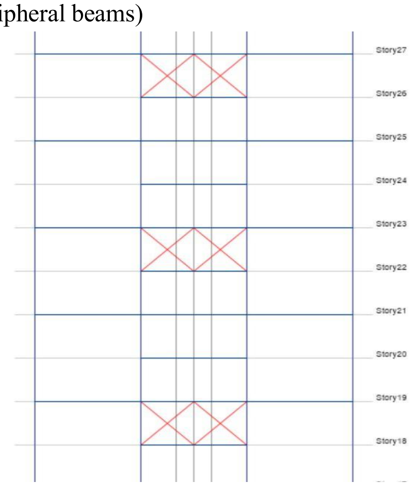


Fig. 8 (a). Elevation view with Outriggers at every 4$^{th}$Floor (Peripheral beams)

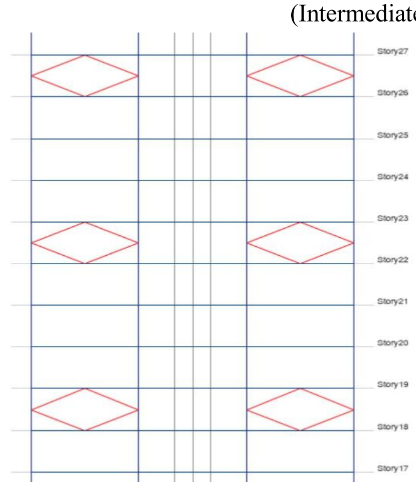


Fig. 8 (b). Elevation view with Outriggers at every 4$^{th}$ Floor (Intermediate beams)

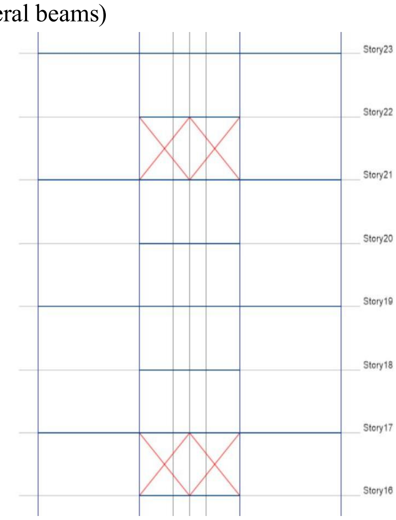


Fig. 9 (a). Elevation view with Outriggers at every 5$^{th}$Floor (Peripheral beams)

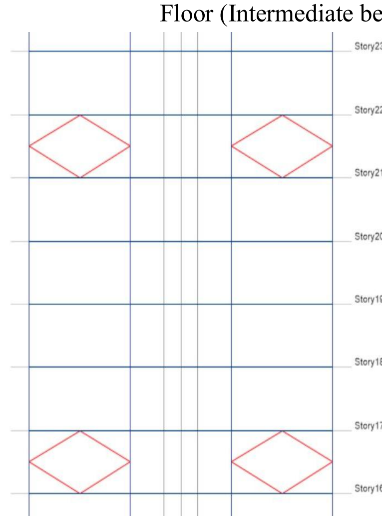


Fig. 9 (b). Elevation view with Outriggers at every 5$^{th}$Floor (Intermediate beams)



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## IV. RESULTS AND DISCUSSION

All the eight models as mentioned above were analysed on ETABS generating results for lateral displacement & storey drift and are plotted with Storey on ordinates & displacement or Storey drift on abscissa:

Lateral Displacement

Distinct colours are employed to differentiate between the various models, while limits specified by IS 1893 (Part 1): 2016 for earthquake load and IS 456: 2000 for wind load are computed for lateral displacement. Additionally, the prescribed limits line is highlighted in red.

Under seismic loading the lateral sway at the top should not be more than $H/_{250}$(i.e $139500/_{250}$ = 558 mm). Similarly under wind loading the lateral sway at the top should not be more than $H/_{500}$(i.e $139500/_{500}$ = 279 mm)

*Grid 6 × 6 m*

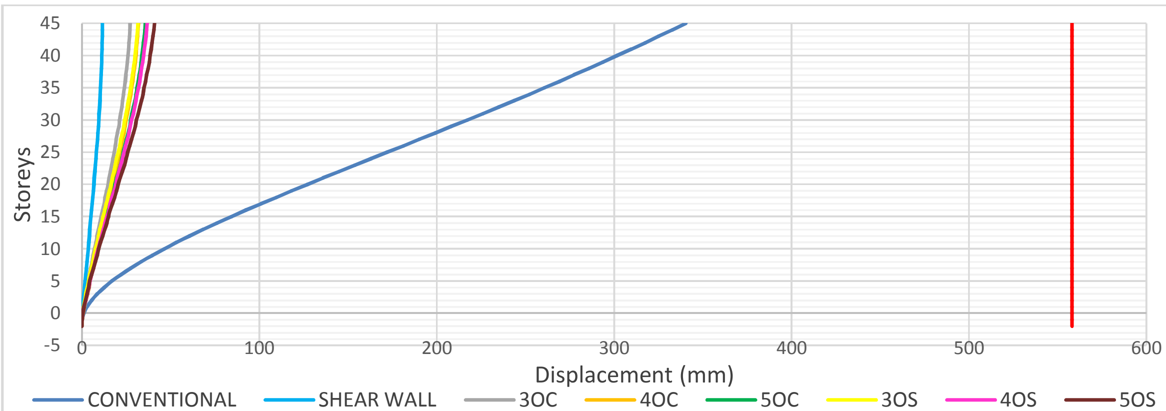


Fig. 10. Displacement Variation for Earthquake load in x-direction for 6 × 6 m grid

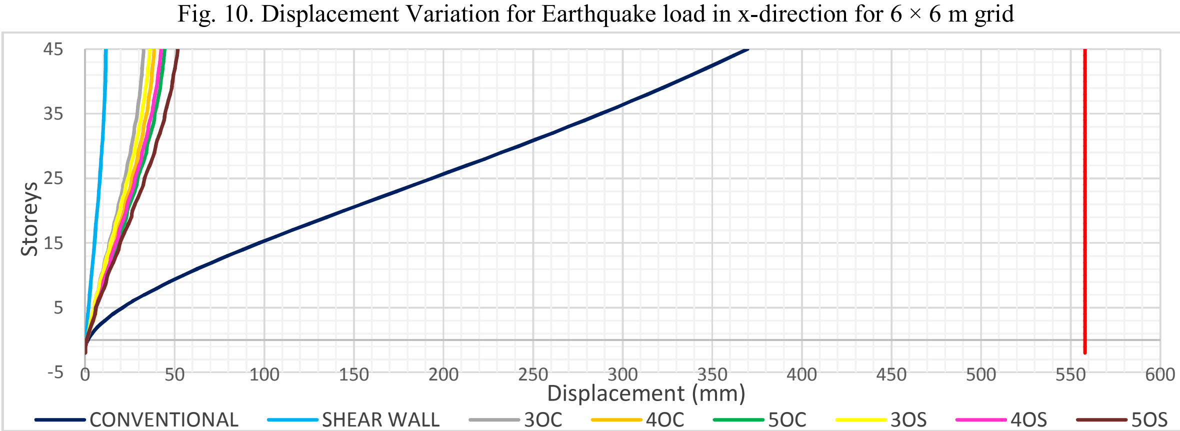


Fig. 11. Displacement Variation for Earthquake load in y-direction for 6 × 6 m grid

The results indicate that the lateral displacement in x& y direction (horizontal movement) during an earthquake is within safe limits for 6 × 6 m grid as per 1893 (Part 1): 2016.

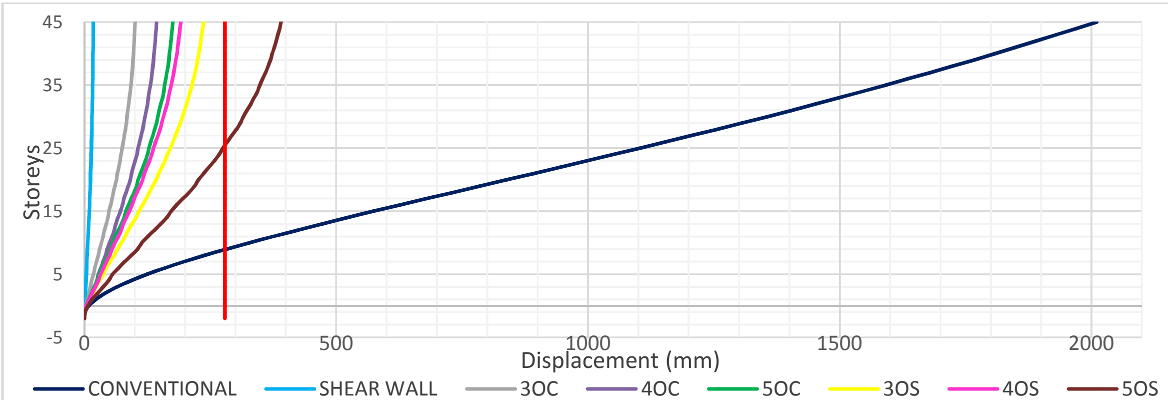


Fig. 12. Displacement Variation for Wind load in x-direction for 6 × 6 m grid

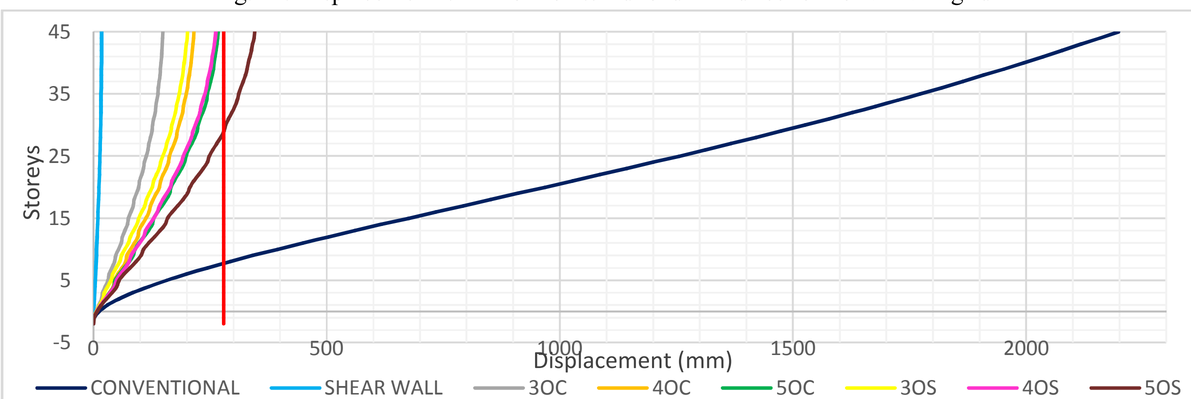


Fig. 13. Displacement Variation for Wind load in y-direction for 6 × 6 m grid

In the context of the 6×6 grid, when subjected to wind loads, all models except the 5OS and conventional ones are deemed safe. This implies that the lateral displacement within the x and y directions falls within acceptable limits as per IS 456:2000 standards. However, the 5OS and conventional models exhibit lateral displacement that exceeds safe thresholds under the same wind loading conditions, rendering them unsafe for this scenario.

**Grid 8 × 8 m**

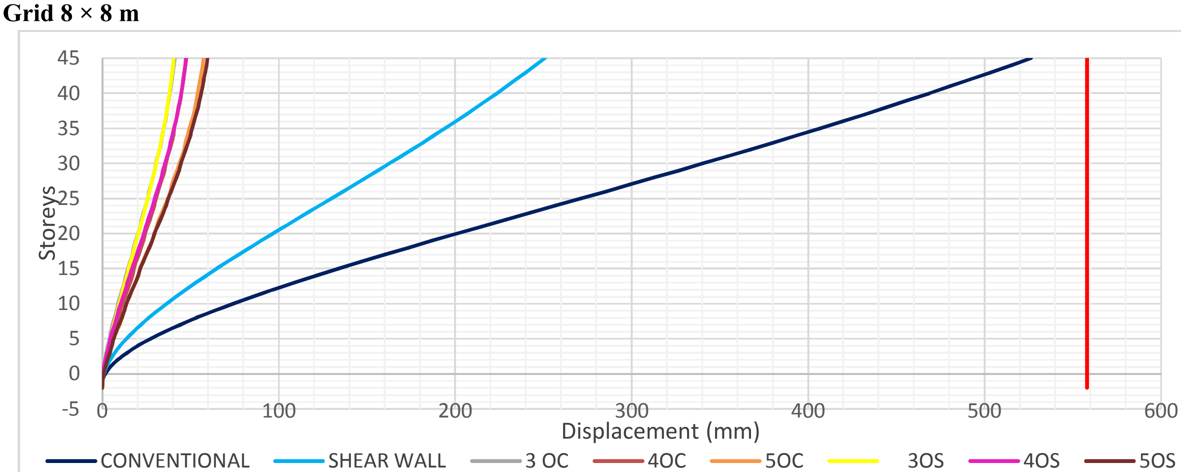


Fig. 14. Displacement Variation for Earthquake load in x-direction for 8 × 8 m grid

If all conditions are deemed safe in earthquake displacement in the x-direction, it indicates that the building's response to seismic forces along this horizontal axis is considered satisfactory or within acceptable limits.

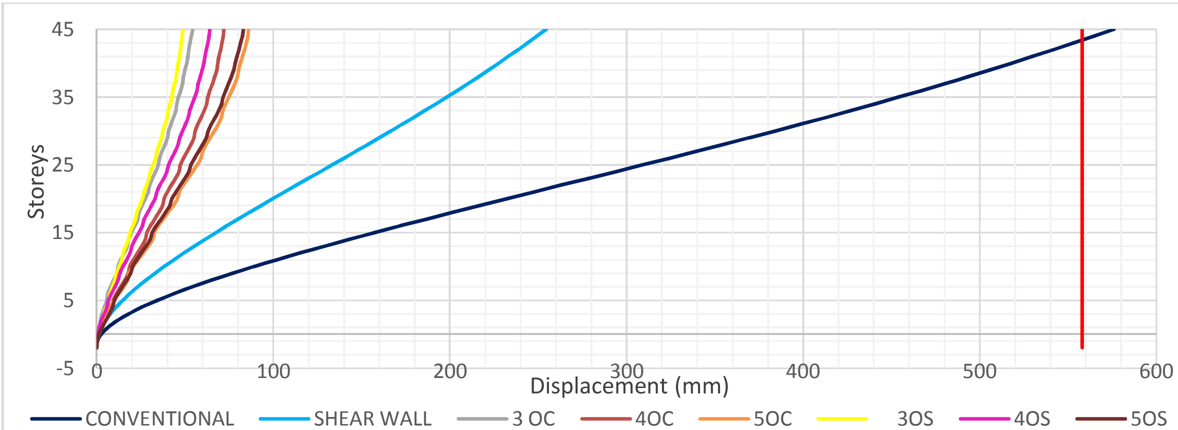


Fig. 15. Displacement Variation for Earthquake load in y-direction for 8 × 8 m grid

In the context of seismic design, model is safe under displacements in earthquake except conventional which likely refers to the fact that structures designed using this model are deemed safe under displacements caused by earthquakes, except for conventional structures.

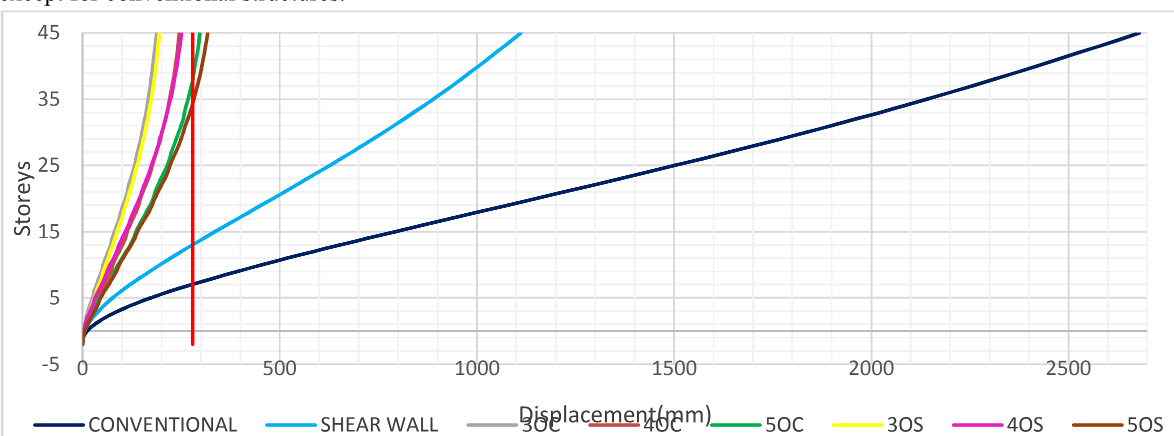


Fig. 16. Displacement Variation for Wind load in x-direction for 8 × 8 m grid

The building's displacement due to wind load in the x direction is generally safe, except for the (5OS) and (5OC), as per IS 875 (Part 3). This implies that specific areas of the building may experience higher displacements and require additional structural considerations or reinforcement to ensure safety against wind forces.


Fig. 17. Displacement Variation for Wind load in y-direction for 8 × 8 m grid

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Above figure represents the displacement of the building under wind loads in the y-direction,Unsafe positions include 4OC, 4OS, 5OS, 5OC, and conventional shear wall, indicating inadequate structural response. Conversely, safe positions like 3OC and 3OS are deemed satisfactory under wind loads.

**Storey Drift Ratio**

Distinct colours are employed to differentiate between the various models, while limits specified by IS 1893 (Part 1): 2016 for earthquake load and IS 456: 2000 for wind load are computed for inter storey drift.

The storey drift ratio in any storey for either seismic or wind loading shall not exceed 0.004 times storey height (i.e. 0.004 × 3= 0.012m)

**Grid 6 × 6 m**

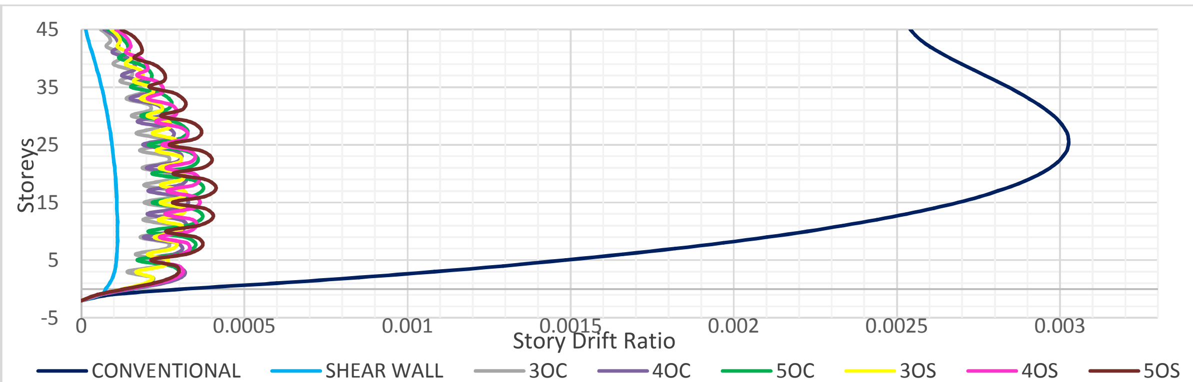


Fig. 18. Inter story Drift Variation for Earthquake load in x-direction for 6 × 6 m grid

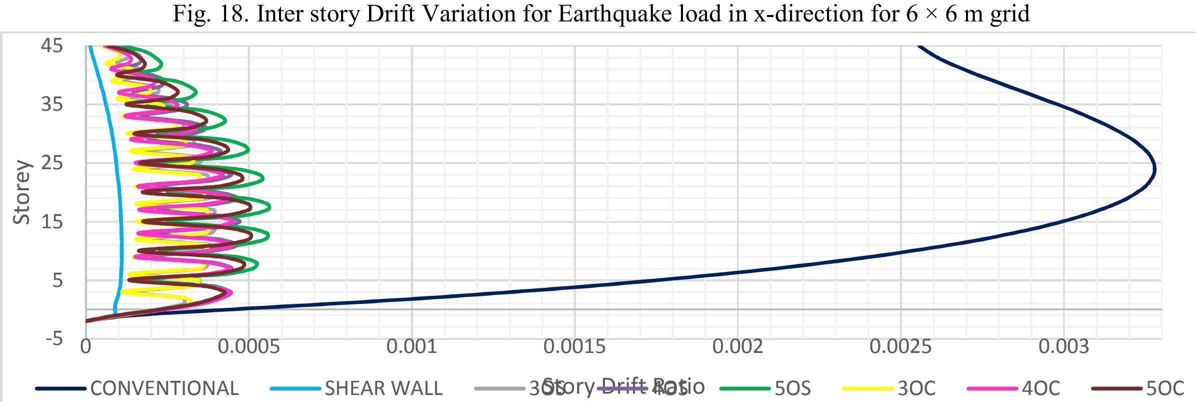


Fig. 19. Inter story Drift Variation for Earthquake load in y-direction for 6 × 6 m grid

All structural models exhibit safety under seismic loading in both the directions when assessed using the storey drift ratio.

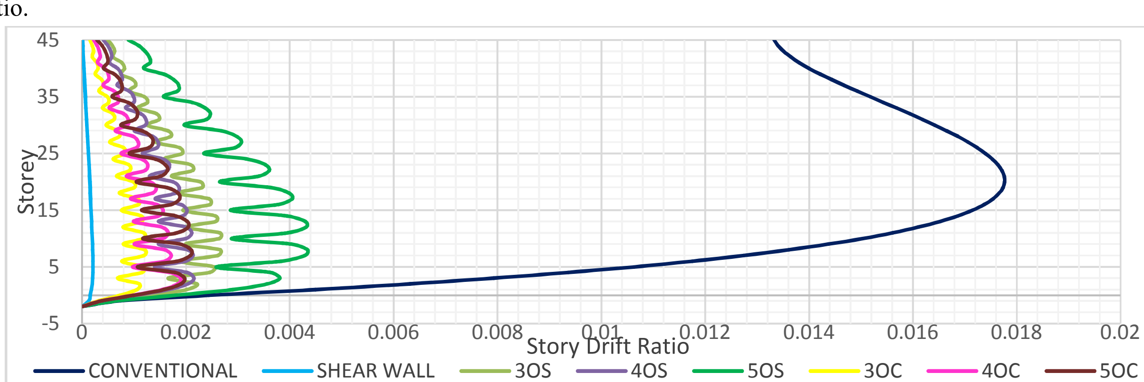


Fig. 20. Inter story Drift Variation for Wind load in x-direction for 6 × 6 m grid

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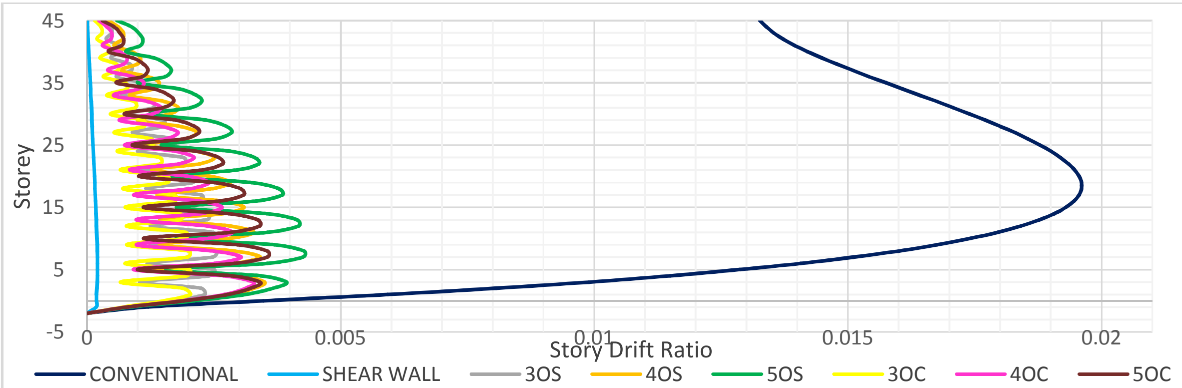


Fig. 21. Inter story Drift Variation for Wind load in y-direction for 6 × 6 m grid

According to IS 1893 (Part 1):2016, all models are deemed safe under wind loads for storey drift ratio in both the direction, except for the conventional model. *Grid 8 × 8 m*

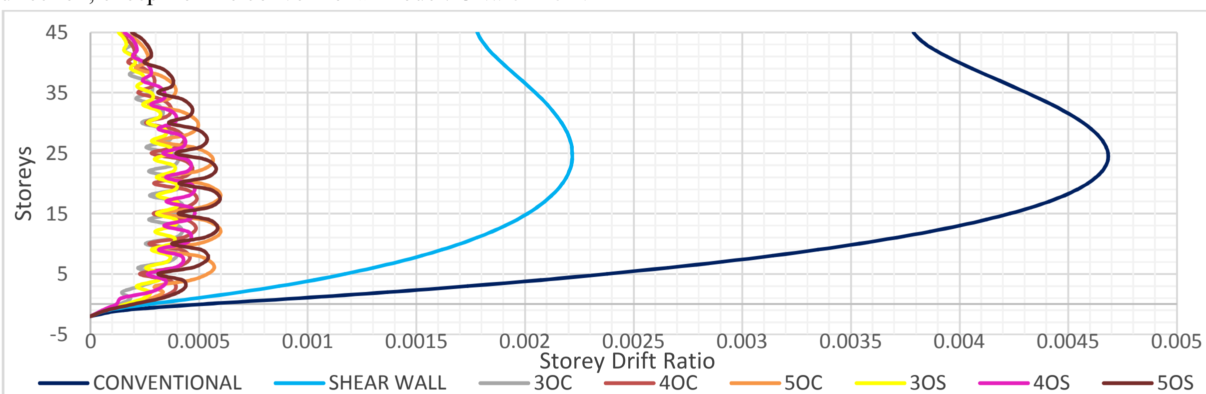


Fig. 22. Inter story Drift Variation for Earthquake load in x-direction for 8 × 8 m grid

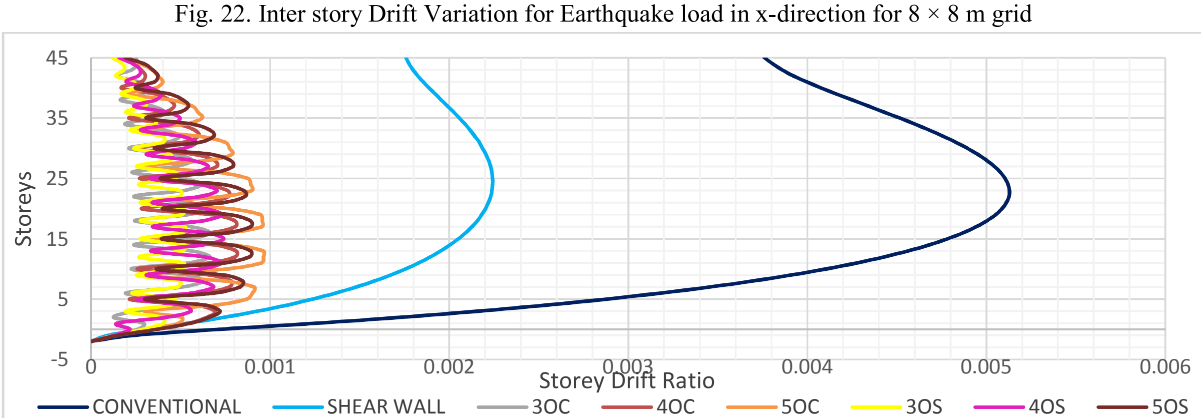


Fig. 23. Inter story Drift Variation for Earthquake load in y-direction for 8 × 8 m grid

Inter story Drift for earthquake in the x-y direction is considered safe for storey drifts according to IS 1893. This means that the structure can withstand seismic forces without exceeding acceptable levels of deformation, ensuring structural integrity and safety during earthquakes.

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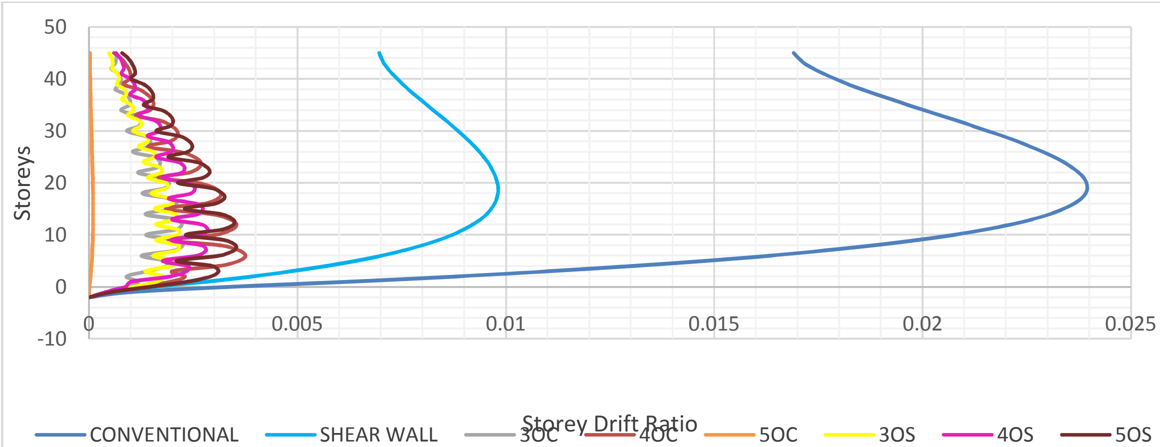


Fig. 24. Inter story Drift Variation for Wind load in x-direction for 8 × 8 m grid

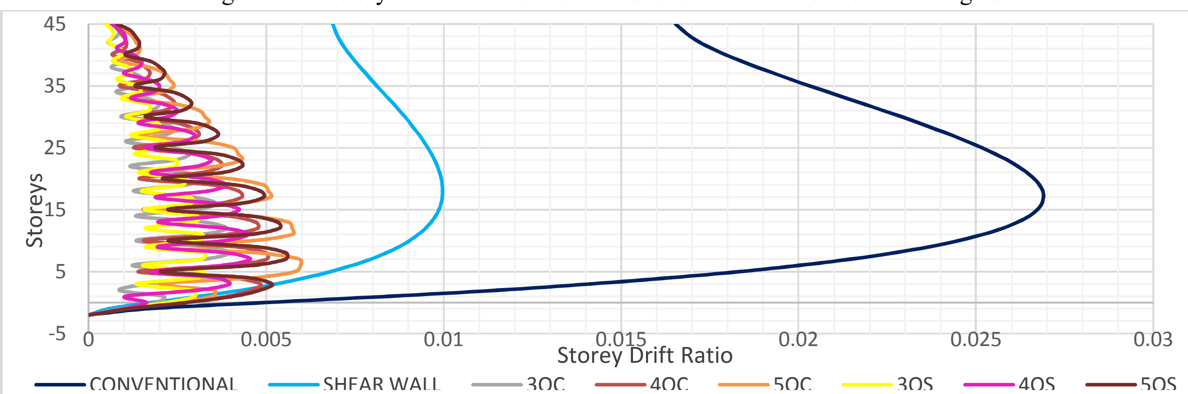


Fig. 25. Inter story Drift Variation for Wind load in y-direction for 8 × 8 m grid

As per IS 1893 (Part1):2016, all models meet safety criteria for story drift ratio under wind load, except the conventional model, which is deemed unsafe. Compliance with the code's specifications ensures structures can withstand wind-induced forces without exceeding acceptable levels of story drift, preventing potential structural damage or failure.

**Cost Comparison**

Costs of all models are compares as per following information:

- Quantity of concrete is calculated in cubic metric.
- Market rate of concrete for M30 grade is taken as ₹ 5570 / $m^3$.
- Quantity of steel is calculated in kg.
- Market rate of steel for Fe 345 grade is taken as ₹ 50 / kg.

TABLE 1: Cost Comparison for 6 × 6 m grid

| Sr.No. | Model | Result | Cost (Rs.) |
|---|---|---|---|
| 1 | SW | Safe | 4,337,804.67 |
| 2 | 3OC | Safe | 1,753,937.30 |
| 3 | 4OC | Safe | 1,286,224.40 |
| 4 | 5OC | Safe | 1,052,340.10 |
| 5 | 3OS | Safe | 8,198,420.49 |

| | | | |
|---|---|---|---|
| 6 | 4OS | Safe | 6,012,174.82 |
| 7 | 5OS | Unsafe | 4,919,051.99 |

The cost of model "3OS" is significantly higher compared to the other models. Models "3OC", "4OC", "5OC", "4OS", and "5OS" have relatively lower costs compared to "SW" and "3OS". If safety is the primary concern, all models except "5OS" would be considered suitable choices. If cost-effectiveness is the primary concern, models like "3OC", "4OC", "5OC", "4OS", and "5OS" could be preferable choices.

TABLE 2: Cost Comparison for 8 × 8 m grid

| Sr.No. | Model | Result | Cost (Rs.) |
|---|---|---|---|
| 1 | SW | Safe | 4,654,793.30 |
| 2 | 3OC | Safe | 1,590,792.00 |
| 3 | 4OC | Safe | 1,313,350.30 |
| 4 | 5OC | Unsafe | 1,156,944.70 |
| 5 | 3OS | Safe | 10,707,294.09 |
| 6 | 4OS | Safe | 8,565,835.37 |
| 7 | 5OS | Unsafe | 6,424,376.15 |

The cost varies across models, with "3OC" being the least expensive and "3OS" being the most expensive. Model "5OC" is labeled as "Unsafe," despite having a relatively lower cost compared to other models labeled as "Safe." Model "3OS" is the most expensive but is labeled as "Safe," indicating that higher cost doesn't necessarily correlate with safety in all cases.

## V. CONCLUSION

In high-rise building analysis, the incorporation of outrigger systems is a common practice to enhance structural stability and mitigate lateral loads such as wind or seismic forces. Outriggers are horizontal structures extending from the core of the building to the perimeter columns, distributing forces and reducing building sway.

When considering different outrigger positions, a 3-storey outrigger system is often deemed safe across various models of high-rise buildings, including those with dimensions of 6x6 and 8x8 This safety is attributed to several factors:

Optimal Distribution of Forces: A 3-storey outrigger system effectively distributes lateral forces, ensuring balanced structural stability throughout the building. The outrigger acts as a link between the core and perimeter columns, transferring loads efficiently.

Reduction of Building Sway: By anchoring the core and perimeter columns together, the outrigger system minimizes building sway, thereby enhancing occupant comfort and structural performance during extreme events such as windstorms or earthquakes.

Flexibility in Design: A 3-storey outrigger configuration offers flexibility in design, accommodating various building sizes and geometries, including those with dimensions of 6x6 & 8x8This adaptability ensures that the outrigger system can be effectively integrated into different structural models while maintaining safety and stability.

Enhanced Structural Integrity: The outrigger system reinforces the overall structural integrity of the building by providing additional support and resisting lateral forces. This results in a robust and resilient high-rise structure capable of withstanding dynamic loads over its lifetime.

Overall, the adoption of a 3-storey outrigger system in high-rise building analysis, regardless of the specific dimensions of the building, offers a safe and reliable solution for optimizing structural performance and ensuring occupant safety.

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