

# ANALYTICAL STUDY OF LATERAL LOAD RESISTANCE OF TALL RCC BUILDINGS WITH VERTICAL STRUCTURAL IRREGULARITIES

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## ABSTRACT

*The increasing urbanization and demand for space in rapidly growing cities have led to the development of tall reinforced cement concrete (RCC) buildings. These buildings, especially those with vertical structural irregularities, often face significant challenges when subjected to lateral loads such as wind and seismic forces. The presence of vertical irregularities can cause non-uniform distribution of forces within the structure, potentially resulting in excessive deflection, torsion, and instability under lateral loads. This study investigates the seismic performance of tall buildings with vertical irregularities, focusing on the impact of outriggers and core walls. The research involves a FEM-based analysis using ETABS software to assess a 20m x 15m reinforced concrete (RC) frame building with a maximum height of G+20 stories, located in seismic zone III. 3 models were analysed to compare the effects of placing an outrigger system at the 10th and 20th floors, in conjunction with core walls. The seismic performance of each model was evaluated in terms of lateral deflection, story drifts, and story shear. Results indicate that the model with the outrigger system at the 10th floor demonstrated a significant reduction in lateral deflection compared to the other models. The use of an outrigger system effectively controlled story drifts and shear forces, thereby improving the overall seismic resilience of the building. This study highlights the importance of optimizing lateral load-resisting mechanisms in tall buildings, particularly in seismic zones, to enhance stability and structural performance.*

**Keywords:** Tall reinforced cement concrete (RCC), Seismic zone, ETABS software

## INTRODUCTION

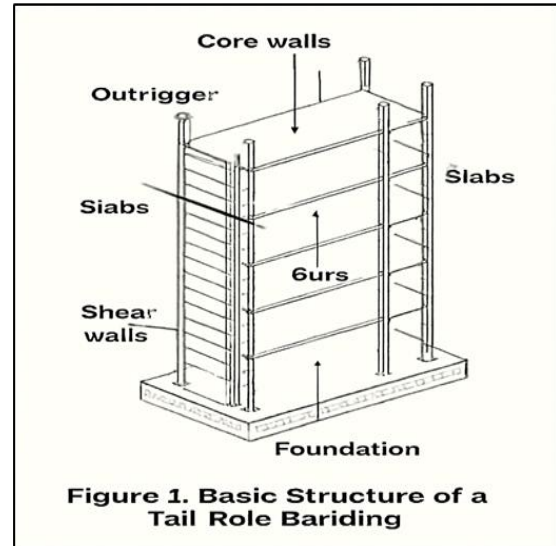
As cities continue to expand, the demand for tall buildings has risen to accommodate the growing population and urban sprawl. These tall structures, particularly RCC buildings, are often chosen for their strength, durability, and ability to support high-rise constructions. However, tall buildings are vulnerable to lateral forces, such as wind loads and seismic forces, which can significantly affect their stability and performance. The challenges become more pronounced when vertical irregularities are present in the structure, such as uneven mass distribution, varying floor heights, or irregular core locations.

Vertical structural irregularities can lead to non-uniform load distribution, resulting in increased stress on certain parts of the building. This can cause excessive deflection, twisting, and even potential collapse under severe lateral loads. To mitigate these issues, modern engineering techniques have incorporated various lateral load-resisting systems like outriggers, shear walls, and reinforced core walls. These systems help distribute lateral forces more evenly and improve the building's resistance to wind and seismic forces. In this study, we explore the behavior of tall RCC buildings with

vertical structural irregularities subjected to lateral forces. Using ETABS software, we simulate different building configurations to assess their seismic performance and lateral load resistance. Determining the most effective structural arrangements and procedures to increase the building's resistance to these forces is crucial for safety and meeting code requirements. Tall buildings, especially in areas vulnerable to earthquakes and severe winds, can benefit greatly from the findings of this study.

### Introduction to Tall RCC Buildings

Tall buildings made of reinforced cement concrete (RCC) are central to modern urbanization, providing essential space in cities where horizontal expansion is no longer feasible. These structures, ranging from residential complexes to commercial skyscrapers, are designed to handle significant loads while maintaining stability. RCC, due to its strength, durability, and flexibility in design, has become the material of choice for tall buildings. RCC tall buildings are typically constructed with a framework of columns, beams, and slabs reinforced with steel to provide structural integrity. The height of these buildings can exceed 20 stories, with some reaching several hundred meters. Tall buildings are particularly vulnerable to lateral pressures like wind and seismic activity because of their elevated locations.



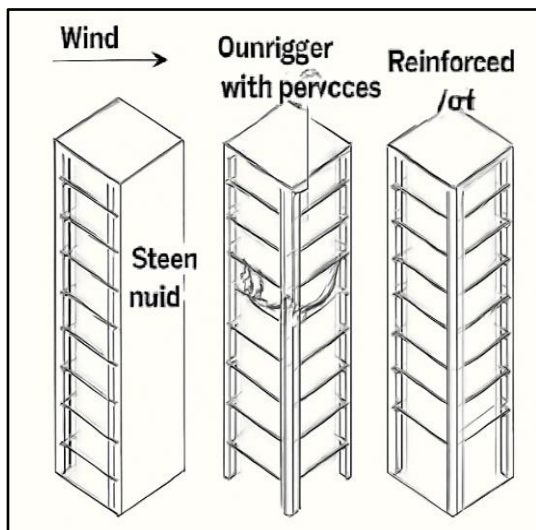
**Figure 1:** Basic Structure of a Tall RCC Building

The figure above illustrates the basic components of an RCC building, including the columns, beams, slabs, and reinforced steel. These elements work together to ensure the structural integrity of the building under various loading conditions. The taller the building, the greater the challenge of ensuring it remains stable under lateral forces.

This diagram would typically depict the key structural elements of a tall RCC building, including:

1. **Foundation:** The base of the structure, often made of reinforced concrete, which supports the entire building. It distributes the loads from the building evenly to the ground.
2. **Columns:** Vertical members that transfer the building's loads from the upper floors to the foundation. RCC columns are reinforced with steel to resist compression and bending forces.

3. **Beams:** Horizontal members that transfer loads from slabs and other elements to the columns. Beams are reinforced with steel to handle bending forces.
4. **Slabs:** Flat horizontal surfaces (floors) of the building that are supported by beams and columns. The slabs are the walking surfaces for the building's occupants.
5. **Core Walls:** Vertical walls typically located at the center of the building, often used to house elevators, stairs, and utilities. They help resist lateral forces and improve the building's stability.
6. **Shear Walls:** Vertical walls that resist lateral forces caused by wind or earthquakes. They are placed strategically in the building to prevent swaying or tipping.
7. **Outriggers:** Structural components that run horizontally from the building's center to its outside columns; they serve to dampen sway and improve resistance to lateral loads.



**Figure 2: Lateral Load-Resisting Systems in Tall Buildings**

In the figure above, various lateral load-resisting systems are shown. Shear walls are vertical elements designed to resist lateral forces, while outriggers are horizontal structural elements that help reduce the building's sway. Reinforced core walls provide stiffness to the building's center, further enhancing its ability to resist lateral forces.

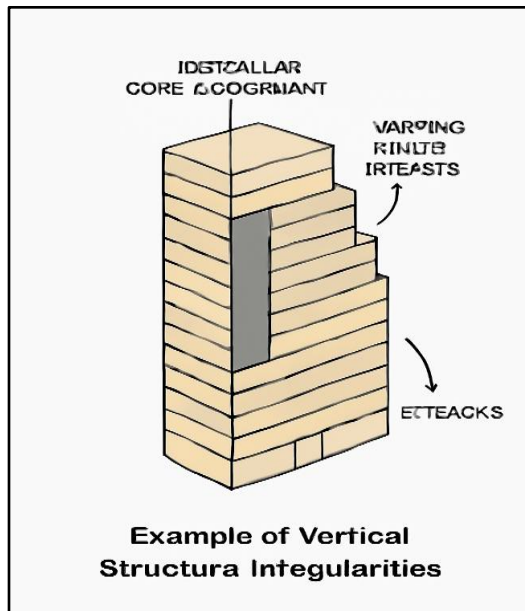
Vertical structural irregularities, such as varying floor heights, uneven mass distribution, and misaligned cores, complicate the performance of tall RCC buildings under lateral loads. These irregularities lead to uneven distribution of forces across the structure, which can cause excessive torsional movement and deflection. Proper analysis and design adjustments are essential to minimize these effects and ensure the building performs optimally under extreme conditions.

In the context of increasing urbanization and the growing trend of vertical construction, the study of tall RCC buildings, especially those with vertical structural irregularities, becomes essential. By better understanding how these buildings behave under lateral loads, engineers can optimize designs to enhance safety, stability, and occupant comfort, ensuring these structures can withstand the demands of modern urban environments.

### **Vertical Structural Irregularities**

Vertical structural irregularities in tall buildings refer to variations in the building's design or geometry along its height that lead to an uneven distribution of mass, stiffness, or strength. These irregularities can significantly affect the

performance of the building under lateral loads such as wind or seismic forces. Vertical irregularities include factors like changes in floor heights, asymmetrical mass distribution, or irregular placement of structural elements such as the core or shear walls. These issues can cause torsion, excessive deflection, or even failure if not addressed during the design phase.



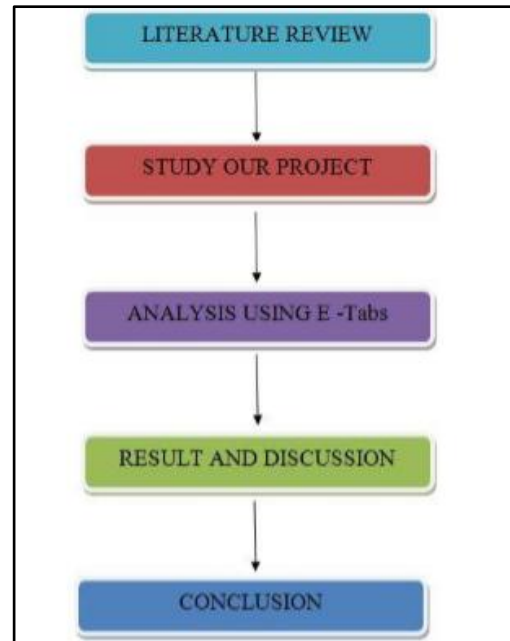
**Figure 3: Example of Vertical Structural Irregularities**

### METHODOLOGY

The methodology of this study focuses on analyzing the lateral load resistance of tall RCC buildings with vertical structural irregularities, using both analytical methods and computational simulations. This approach allows for a detailed understanding of how these irregularities affect the building's stability under lateral forces such as wind and seismic loads. The steps involved in the methodology include the selection of the building model, the identification of structural irregularities,

the use of computational tools for analysis, and the evaluation of performance under different load conditions.

### Selection of Building Model



**Figure 4: Design flow chart**

In this study, three distinct methods will be used to evaluate the lateral load resistance of tall RCC buildings with vertical structural irregularities: the Linear Static Method, the Linear Dynamic Method, and the Finite Element (FE) Method. Each of these methods provides different levels of insight into the building's behavior under lateral forces, and their application allows for a comprehensive analysis of how vertical irregularities affect a building's stability under dynamic loads such as wind and seismic forces.

### Analyzing the data

In accordance with IS 1893 (Part 1): 2002, the ETABS analysis program has been used to conduct linear dynamic analysis on

each model. We distribute the lateral loads and self-weights along the building's elevations after we calculate them. By adding 25% of the live load to the complete dead load, we can calculate the seismic load.

**Table : Following data is used in the analysis of the tall RC frame building models**

Parameter	Details
Type of frame	(OMRF) Ordinary Moment Resisting RC frame fixed at the base of the tall building
Seismic zones	III
Number of stories	G+20 stories
Floor height	3 m
Size of beam	(300 × 400) mm
Size of column	(300 × 600) mm
Spacing between frames in x-direction	20 m
Spacing between frames in y-direction	15 m
Materials	M 25 concrete, Fe 415 steel
Type of section of outrigger system	Channel section
Position of outrigger system	10th and 20th stories
Infill (shear wall)	Brick
Density of concrete	24 KN/m <sup>3</sup>

Parameter	Details
Density of infill	20 KN/m <sup>3</sup>
Type of soil	Medium soil
Seismic zone	As per IS 1893-2002
Seismic zone factor, Z	For zone II: 0.10, For zone III: 0.16, For zone IV: 0.24, For zone V: 0.36
Importance Factor, I	1
Type of seismic analysis	Linear static analysis

**Materials used**

**a) Concrete**

Concrete with following properties is considered for study.

- Characteristic compressive strength ( $f_{ck}$ ) = 25 MPa
- Poissons Ratio = 0.2
- Density = 24KN/m<sup>3</sup>
- Modulus of Elasticity (E) = 5000 x  $\sqrt{f_{ck}}$  = 25000 MPa

**b) Steel**

Steel with following properties is considered for study.

- Yield Stress ( $f_y$ ) = 415 MPa
- Modulus of Elasticity (E) = 2x10<sup>5</sup>MPa

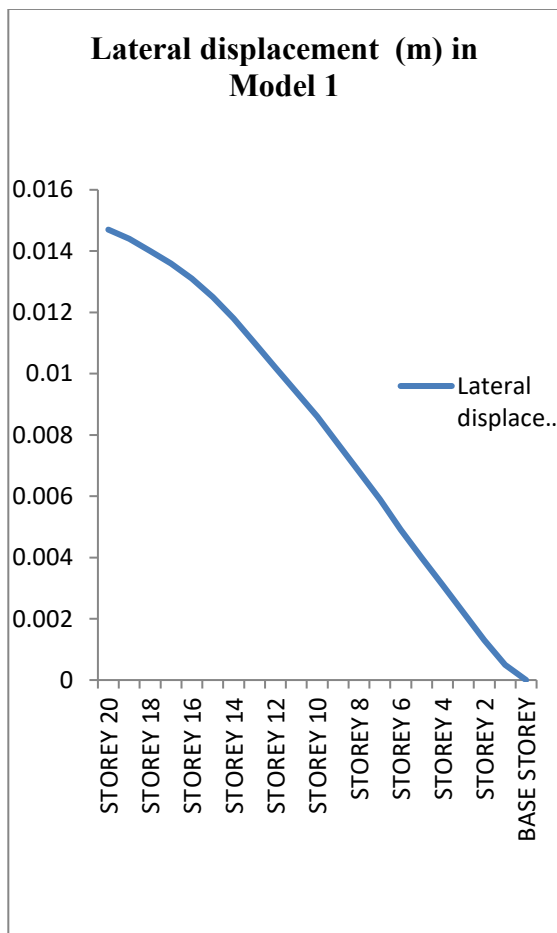
**RESULTS AND DISCUSSIONS**

All models are subjected to a linear dynamic analysis. Loads are computed and distributed using ETABS in accordance with IS 1893 (Part I):2002 code. The findings of the analysis are contrasted with

regard to the following factors. Three models were analysed, including the frame models and the tall building's bare frame with outrigger system and shear wall at the core. ETABS is used for the linear static analysis. For all Models in zone III, storey drifts, lateral displacement, and storey shear were Studied.

**a) Results and discussion in model 1 (Bare frame)**

**Lateral displacement: Lateral displacement in seismic zone III**

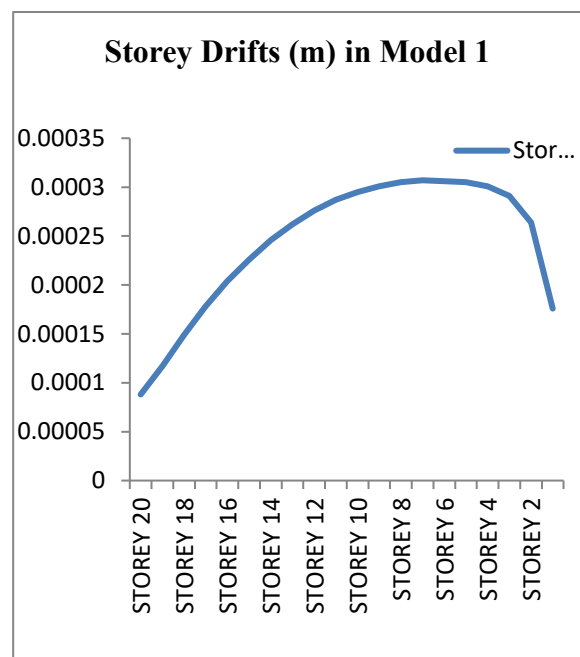


**Fig 5: Lateral displacement in seismic zone III in Model 1**

Figure 18 shows that, in model 1 (Bare frame), the lateral displacement increases from the first to the twentieth story. This is

because, over time, the bare frame is subjected to external stresses including living, wind, and seismic loads, which cause it to gradually shift. The structural behavior of towering buildings, such as skyscrapers, causes the first to deflect far less than the second, especially when the building's mass source is located in the middle of the structure.

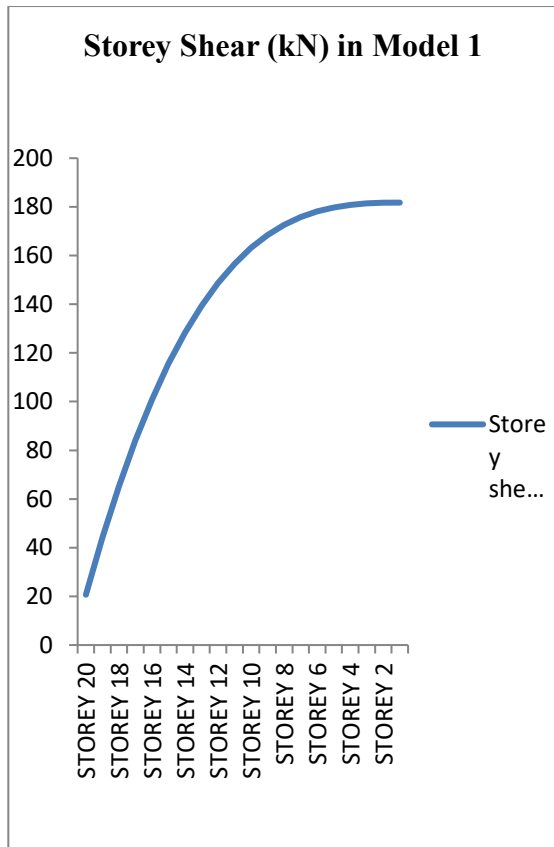
**Storey drifts: Storey drifts in seismic zone III**



**Fig 6: Storey drifts in seismic zone III in Model 1**

In seismic zone III, the storey drift was less at the 20th storey and more at the 7th story of the tall building, as shown in the findings of storey drifts for model 1 (Bare frame) in Fig. 19. The horizontal displacement between storeys, measured in units of less than 0.04 h, is called the storey drifts.

**Storey shear: Storey shear in seismic zone III**

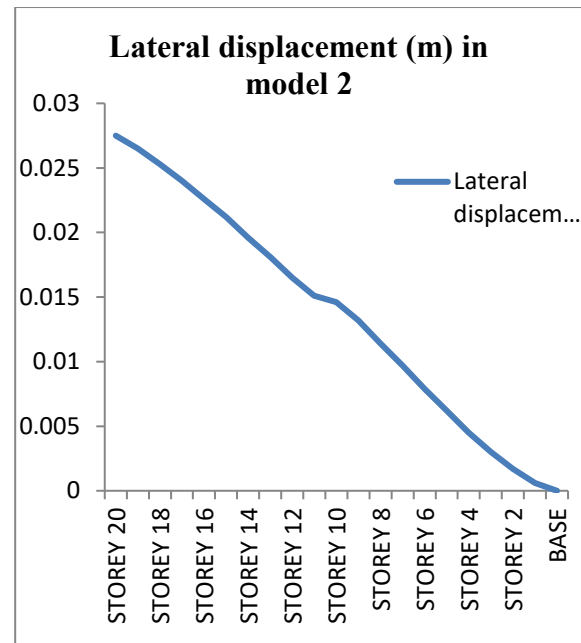


**Fig 7: Storey shear in seismic zone III in Model 1**

In the results of storey shear for model 1 (Bare frame), shown in Fig. 20, we can see that there is more shear at the first storey and less at the twentieth. This is because the total load of the structure is distributed from the bottom to the top in a decreasing order, resulting in more shear at the bottom and less at the top.

**b) Results and discussion in model 2 (Bare frame with outrigger system)**

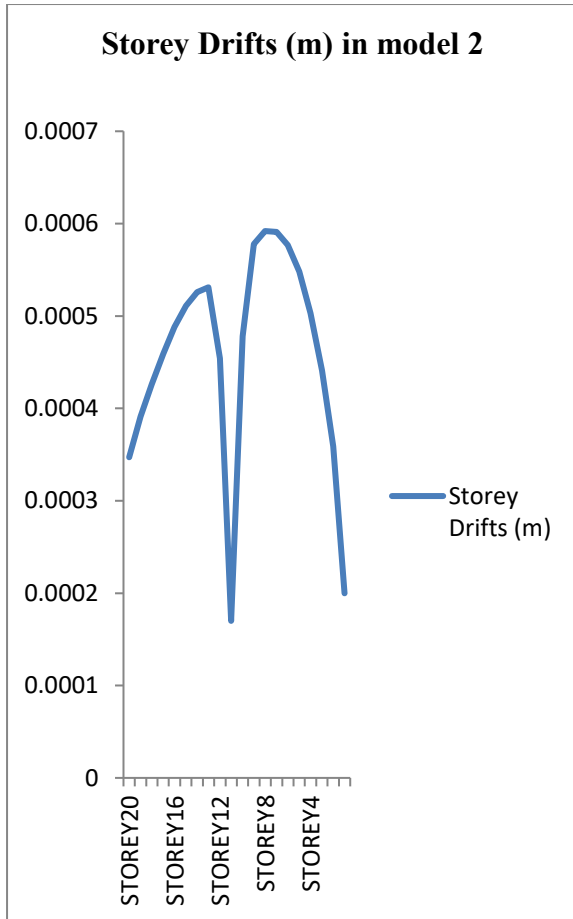
**Lateral displacement:** Lateral displacement in seismic zone III



**Fig 8: Lateral displacement in seismic zone III in Model 2**

According to the results examined in zone III and the observed lateral displacement, the lowest lateral displacement was found at the first storey and the highest at the twentieth. In this case, a small change (a decrease in lateral displacement) occurred at the eleventh storey as a result of the outrigger being retained at the tenth storey of the tall building.

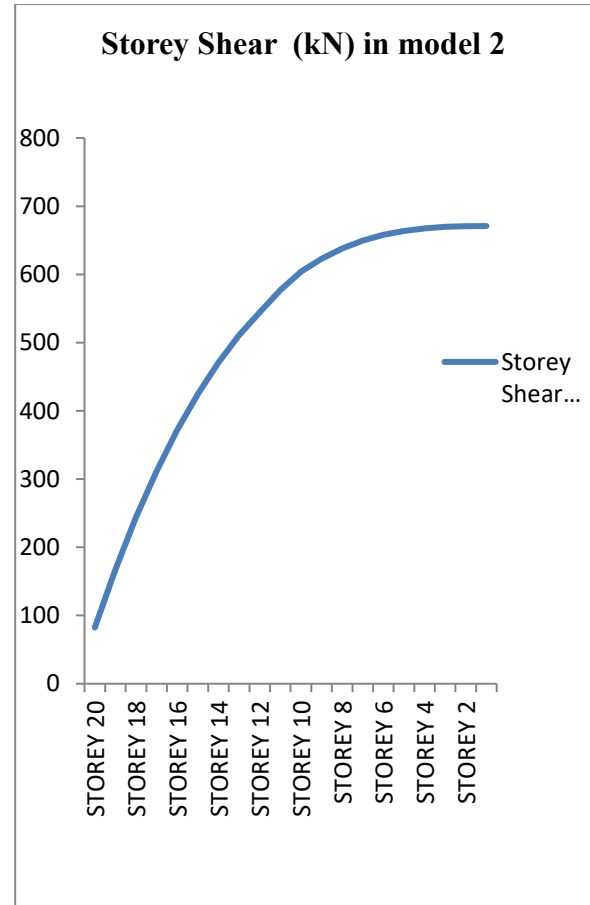
**Storey drifts: Storey drifts in seismic zone III**



**Fig 9: Storey drifts in seismic zone III in Model 2**

The graph up there shows the storey drifts and zone III results. The outrigger on the tenth floor of the tall building causes the most lateral displacement on the eighth floor, while the lowest storey drifts happen on the eleventh. An outrigger system regulates the storey drift in structures with many stories.

**Storey shear: Storey shear in seismic zone III**

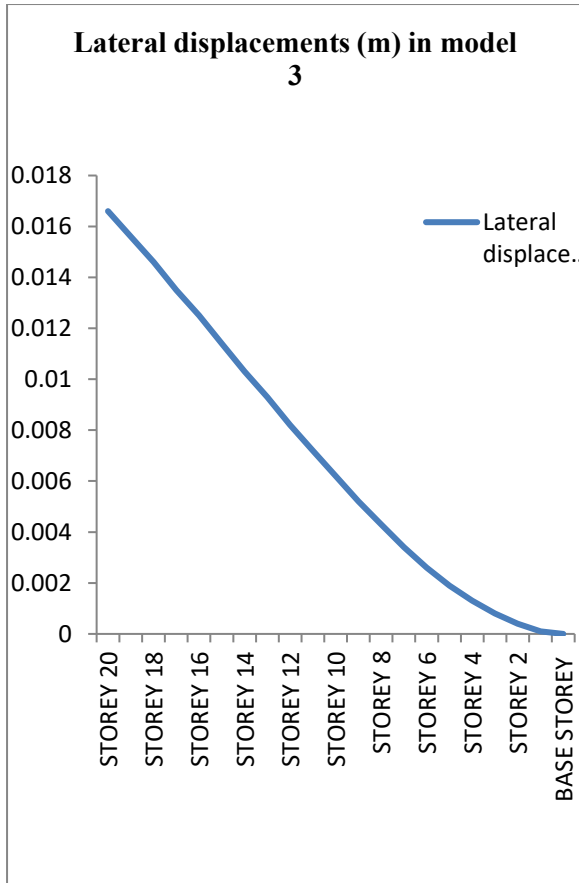


**Fig 10: Storey shear in seismic zone III in Model 2**

The results for zone III and storey shear have been seen in the graph above; the lowest storey drifts are at the 20th storey, the highest lateral displacements are at the 1st storey, and the storey shear has changed progressively from the 20th to the 1st storey in this case.

**Results and discussions in model 3 (Bare frame with double outrigger system)**

**Lateral displacement: Lateral displacement in seismic zone III**

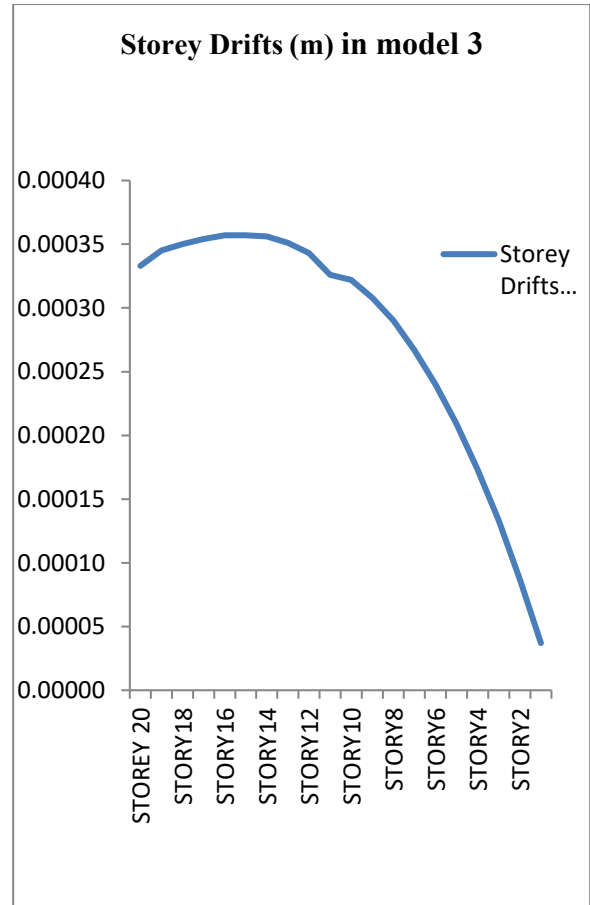


**Figure 11: Lateral displacement in seismic zone III in model 3**

From above graph, the lateral displacements has been studied and observed in tall building of

The tall building reached its maximum height of 20 stories, with the lowest lateral displacement recorded on the first floor and the greatest lateral displacement on the twentieth. The entire structure has been reinforced and made more rigid by positioning the outriggers at the tenth and twentieth stories. There was a reduction in lateral displacement as well.

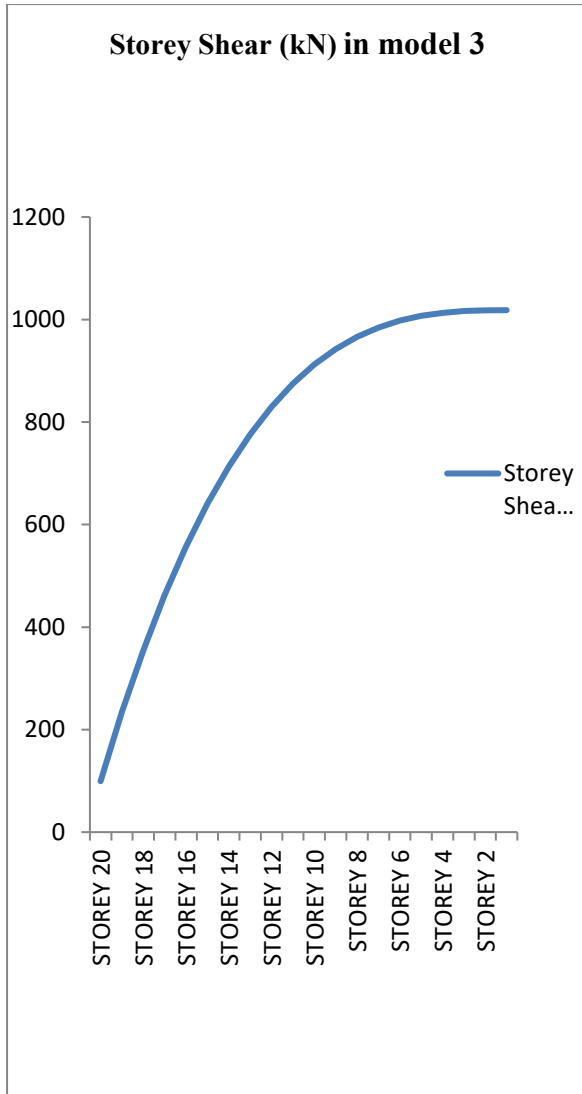
**Storey drifts: Storey drifts in seismic zone III**



**Fig 12: Storey drifts in seismic zone III in model 3**

Studying and observing storey drifts in 20-story tall buildings yielded the following results: the lowest lateral displacement was found on the first floor, and the highest storey drifts were found on the fifteenth floor. The outrigger is maintained at the tenth and twentieth stories.

**Storey shear: Storey shear in seismic zone III**

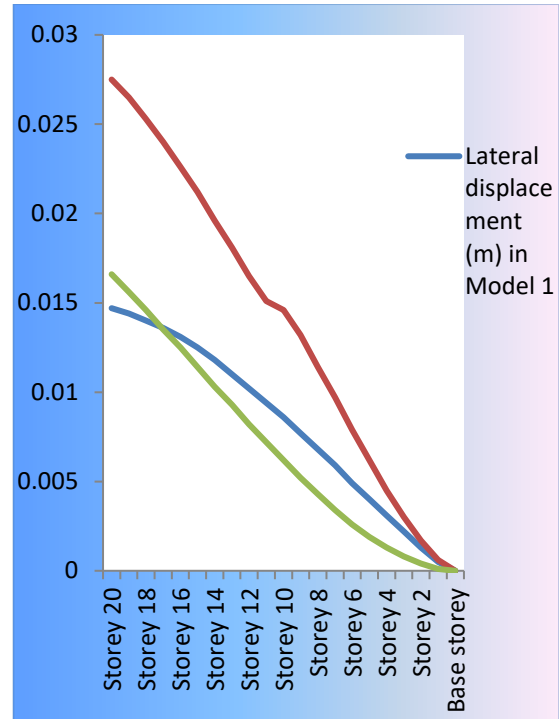


**Fig 13: Storey shear in seismic zone III in model 3**

The following graph shows the results of a study on storey shear in a 20-story building: the lowest shear was found at the 20th floor, the highest at the 1st, and the outriggers were placed at the 10th and 20th floors, respectively.

**Comparative study of lateral displacement, Storey drifts and Storey shear from model 1, model 2 and model 3**

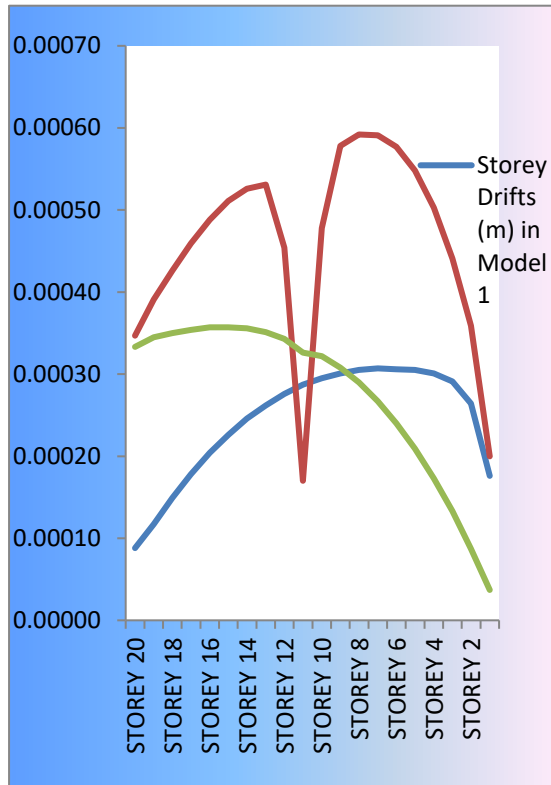
**a) Comparison of lateral displacements in model 1, model 2 and model 3**



**Fig 14: Comparison of lateral displacements in model 1, model 2 and model 3**

The lateral displacement in seismic zone III has been examined in models 1, 2, and 3, as shown in the graph above. Due to the outrigger system at the 10th floor of the building, model 2 exhibited more displacement than models 1 and 3. Also, the outriggers on the skyscraper's tenth and twentieth floors reduced the lateral displacement in model 3. In light of the foregoing, it is clear that Model 3 (with outriggers at the 10th and 20th stories) was the more robust and stable of the two buildings. In order to reduce lateral movement and increase rigidity, tall buildings often employ outrigger structural systems. A building with an outrigger structural system is better able to withstand wind and seismic forces.

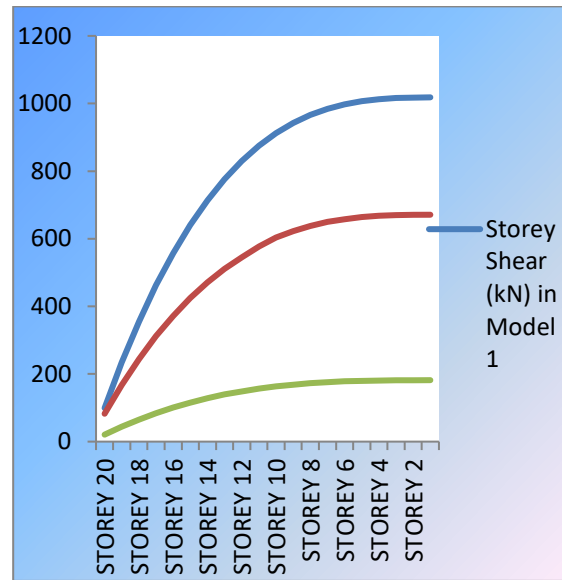
**b) Comparison of Storey drifts in model 1, model 2 and model 3**



**Figure 15: Comparison of Storey drifts in model 1, model 2 and model 3**

Based on the data shown in the graph, three different models were used to study storey drifts in seismic zone III. Model 2 had the highest storey drifts because its outrigger system was installed at the 10th storey, while model 3 had the lowest storey drifts because its outrigger system was installed at the 10th and 20th storeys. Therefore, compared to the other two models, model 3 is more stable. Controlling the lateral story drifts in this location were the outrigger system and core wall. By incorporating outriggers into tall structures, the load-resisting capacity can be enhanced thanks to their inherent strength.

**Comparison of Storey shear in model 1, model 2 and model 3**



**Fig 16: Comparison of Storey shear in model 1, model 2 and model 3**

Model 3 shows the lowest storey shear and model 1 the highest, according to the following graph, which analyses storey shear in seismic zone III. Adding an outrigger, which is a strong structural component, boosts the load-resisting ability of tall buildings. When an outrigger system is placed near the center of the structure, it helps manage movement conditions and ensures minimum shear. The results show that the storey shear is controlled by the outrigger system.

**CONCLUSIONS**

The analytical study on the lateral load resistance of tall RCC buildings with vertical structural irregularities reveals that such irregularities significantly affect the building's ability to withstand lateral forces like wind and seismic loads. These irregularities, which include variations in floor heights, setbacks, and mass

distribution, can lead to uneven force distribution, resulting in increased torsional effects and potential weaknesses in the structure. Buildings with vertical irregularities often exhibit greater displacements and drift, particularly during seismic events. Based on the analytical study of lateral load resistance in tall reinforced concrete (RCC) buildings with vertical structural irregularities, several key conclusions can be drawn:

#### **Impact of Vertical Irregularities on Structural Performance:**

- Vertical structural irregularities, such as setbacks, varying floor heights, or mass distribution, significantly affect the lateral load resistance of tall buildings.
- These irregularities lead to uneven distribution of forces across the building, potentially creating weak points that may experience higher lateral forces during events like earthquakes or high winds.
- Buildings with vertical irregularities show higher torsional behavior, which can lead to inefficient load distribution and, in some cases, structural failure if not properly accounted for in the design phase.

#### **Importance of Proper Modeling and Analysis:**

- The study highlighted the importance of accurate and detailed modeling of such irregularities during the design and analysis phases. This ensures that engineers can anticipate the potential impacts of irregularities on the building's performance.
- Advanced structural analysis tools, such as ETABS or other finite element-based software, provide the necessary simulation capabilities to assess the

dynamic behavior of such buildings under lateral loads.

- A precise modeling approach helps engineers to optimize the placement of shear walls, bracing systems, or outriggers to mitigate the adverse effects of these irregularities.

#### **Enhanced Lateral Load Resistance with Structural Modifications:**

- The study showed that incorporating additional structural elements like shear walls or braced frames can significantly improve the lateral load resistance of buildings with vertical irregularities.
- Proper reinforcement and the use of rigid cores or outriggers, especially at critical levels (e.g., mid-height or top floors), can substantially reduce torsional effects and increase overall stability.

#### **Seismic Considerations and Safety:**

- Tall buildings with vertical irregularities are more vulnerable to seismic forces, especially in high seismic zones. The study emphasized the need to evaluate buildings in seismic regions more rigorously, considering both static and dynamic effects.
- Seismic analysis revealed that buildings with irregularities may experience greater displacements and drift, which could endanger the structural safety and occupant comfort during an earthquake. Design codes and safety standards should reflect these challenges to ensure structural integrity under seismic loads.

#### **Code Compliance and Design Recommendations:**

- The findings of this study support the idea that buildings with vertical irregularities require special design considerations, as stipulated by international building codes (e.g., IS 1893, IBC).

- Engineers must incorporate the relevant provisions for torsional resistance, non-linear behavior, and drift control in their design process to ensure compliance with these codes.
- It is recommended that more stringent checks be made for buildings with vertical irregularities, particularly in areas of high seismic activity, to ensure that lateral loads are resisted effectively and that the building is safe for occupancy.

#### Future Research and Development:

- The study concludes with a suggestion for further research to explore new structural systems and materials that could better mitigate the effects of vertical irregularities in tall buildings.
- There is also an opportunity to refine modeling techniques to account for the complex interaction between irregularities and lateral loads, considering factors such as soil-structure interaction, building sway, and dynamic response under varying load conditions.

In summary, the analytical study underscores the importance of addressing vertical structural irregularities in tall RCC buildings to optimize lateral load resistance. With the proper design strategies and advanced analysis methods, it is possible to ensure that such buildings perform safely under lateral forces, particularly in seismic regions.

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