Impact of Stiffness Irregularity on the Wind Response of Multi-Storey Vertical Irregular Structures

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Abstract—This study examines the wind response of a 35-story vertically irregular building with varying floor heights at selected levels to simulate stiffness discontinuities. Using ETABS 2022, analysis is performed in accordance with IS 16700:2017 and relevant wind codes. Results indicate that irregularities at lower and mid-levels (ground and 17th floors) significantly increase displacement and shear, making the structure more vulnerable, while irregularities at higher levels (24th and 34th floors) show comparatively lesser impact. Wind analysis further highlights changes in lateral resistance and torsional effects at irregular stories. The study concludes that vertical stiffness irregularities must be carefully managed, recommending retrofitting and optimized member dimensions at critical floors to enhance structural safety.

Index Terms—Irregular building, wind, ETABS, Response Spectrum

1. INTRODUCTION

Making a building earthquake-resistant has become a crucial thing in the current time, especially in high-rise structures. Modern architectural and functional demands often introduce vertical irregularities, such as sudden changes in stiffness, mass, or geometry, which significantly enhance a building's dynamic response. Among these, stiffness irregularity is particularly critical, as abrupt reductions in lateral stiffness at certain storey levels can cause localized deformation and increased vulnerability during high wind events. Although design codes and advanced analytical tools provide guidelines, understanding the behavior of vertically irregular structures remains essential for ensuring safety, serviceability, and the effectiveness of performance-based design.

1.1 Vertical Irregularities

Vertical irregularity in buildings arises from non-uniform distribution of mass, stiffness, or geometry along their height, and is a critical factor influencing heavy wind performance. Common forms include mass irregularity due to sudden changes in floor loads, stiffness irregularity or soft storey caused by reduced lateral resistance, geometric irregularity from setbacks or tapering, and vertical discontinuities from weak columns or walls. These irregularities can lead to increased inter-storey drifts, torsional effects, and soft-storey mechanisms, significantly raising the risk of structural damage or collapse, as seen in past earthquakes like Kobe (1995) and Bhuj (2001). Recognizing these risks, design codes such as IS 1893, ASCE 7, and Eurocode 8 classify vertical irregularities and mandate stricter design provisions to ensure structural safety

1.2 Plan Irregularities

Plan irregularity in structural systems arises when a building exhibits asymmetry or discontinuity in its horizontal configuration, thereby inducing complex torsional responses under seismic and wind excitation. Such irregularities compromise the uniform distribution of lateral forces, leading to stress concentrations, eccentric load paths, and samplified deformation demands in specific structural components. Torsional irregularity manifests when mass and stiffness are asymmetrically distributed, causing the building to rotate excessively about its vertical axis. Re-entrant corner irregularity occurs in L-, T-, or U-shaped layouts, where discontinuities create zones of stress concentration and potential separation during wind motion.

Diaphragm discontinuity irregularity is associated with sudden reductions in diaphragm stiffness or the presence of large openings, which interrupt the efficient

transfer of inertial forces. Out-of-plane offset irregularity arises when vertical elements such as columns or walls are discontinuously aligned in plan, resulting in abrupt load path deviations and structural instability. Non-parallel systems irregularity is characterized by lateral force-resisting elements arranged in non-orthogonal orientations, complicating the global response. Collectively, these irregularities significantly escalate torsional demands, undermine redundancy, and necessitate stringent design considerations as mandated by IS codes to mitigate catastrophic structural failures

1.3 Wind analysis

The wind load analysis was conducted as per IS 875 (Part 3):2015, considering the basic wind speed of 47m/s for the 4 (terrain category) region, with an appropriate risk coefficient (k1), terrain roughness factor (k2), and topography factor (k3). The design wind pressure (Pz) was computed for different building heights, and the results were compared with the code-specified limits to ensure structural stability under cyclonic/storm conditions.

2. METHODOLOGY

This study investigates the wind performance of RCC high-rise buildings (G+35) with varying floor-to-floor heights in Seismic Zone IV on medium soil. The models were developed in ETABS 2022 and analyzed using the dynamic Response Spectrum Method. Variations in shear wall thickness and reinforcement were introduced to study their effect on wind behavior. Critical parameters such as storey displacement, inter-storey drift were evaluated. Performance points and energy dissipation patterns were also considered to understand structural stability. The findings were validated against code provisions and past experimental studies. The research aims to highlight the impact of building height and stiffness irregularity on wind response. Finally, it provides practical design recommendations for optimizing RCC building performance in high wind regions.

RCC structures (G+35) were modelled in ETABS 2022 to analyse wind performance with Response Spectrum. Different shear wall thicknesses and reinforcement were applied in ZONE IV to assess their influence on seismic behaviour. The modelling process follows these steps:

1. Create Grid & Generate Structure – Define grid lines and model the building geometry.
2. Define IS Code – Select Indian Standards for wind and design parameters.
3. Define Materials & Sections – Input concrete and steel properties; create beam, column, and slab sections.
4. Assign Sections & Modifiers – Apply defined sections to structural elements and adjust property modifiers if needed.
5. Assign Diaphragms & Supports – Provide rigid diaphragms at each floor and fix supports at the base.
6. Define Loads & wind Parameters – Specify dead, live, and wind load cases as per IS 875 part 3.
7. Assign Loads – Apply dead, live, and additional loads to structural elements.
8. Assign Mass Source – Define the source for seismic mass calculation.
9. Define Response Spectrum – Input zone factor, damping ratio, soil type, and spectrum data as per IS 1893.
10. Assign Load Combinations – Generate strength and service load combinations per IS 456 and IS 1893.
11. Run Analysis – Perform structural analysis to obtain wind responses.
12. Verify Results – Check base shear, storey displacements, and drift limits against IS provisions.
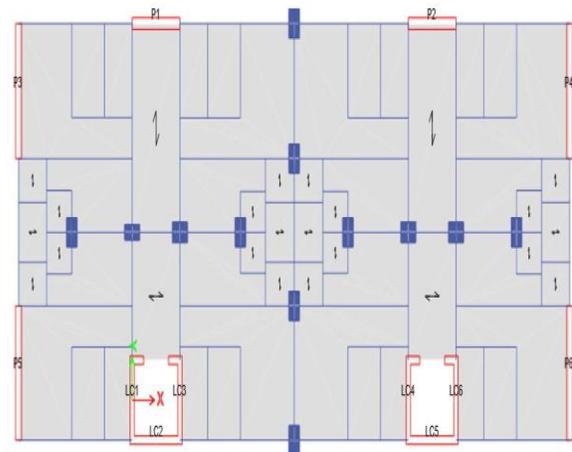13. Save & Document – Save the model, export results, and prepare documentation.

Fig -1: ETABS model for G+35 structure (Plan)

Table -1: ETABS models

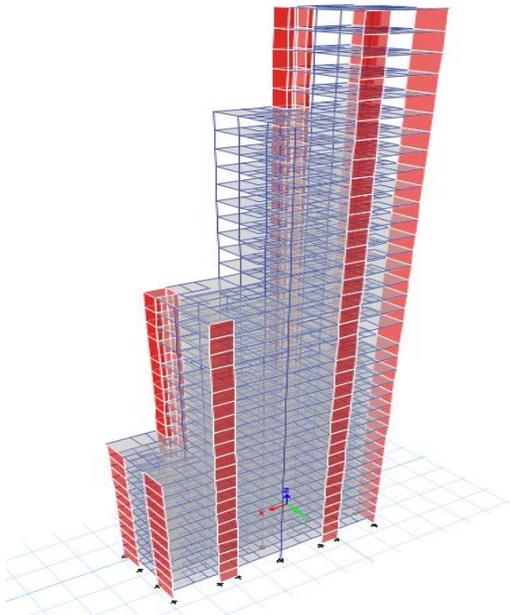| Model no.	Total Stories	Configuration
1	G+35	Same Floor height for all levels
2	G+35	Change in floor height at ground level
3	G+35	Change in floor height at 17th level
4	G+35	Change in floor height at 24th level
5	G+35	Change in floor height at 35th level

Fig -2: ETABS for G+35 structure (3D)

3. RESULT

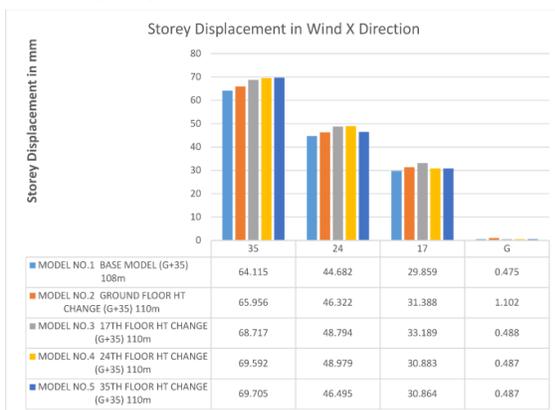### 3.1 Storey displacement X direction

Chart -1: Storey displacement X direction

3.2 Storey displacement Y direction

Chart -2: Storey displacement Y direction

3.3 Story drift X direction:

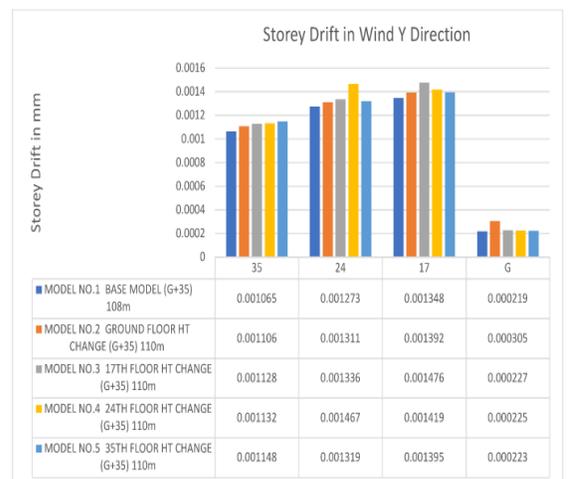Chart -3: Story drift X direction

3.4 Story drift Y direction:

Chart -4: Story drift Y direction

3.5 Modal Participating Mass ratio :

Table -2: Modal Participation for the model with height change

Modal participating mass ratios			
Mode	UX	UY	RZ
1	8%	52%	12%
2	63%	1%	1%
3	1%	7%	62%
4	17%	1%	1%
5	1%	17%	4%
6	1%	1%	7%
7	3%	1%	2%
8	4%	1%	6%
9	3%	2%	3%
10	1%	3%	2%
11	2%	0%	1%
12	1%	3%	1%

Table -3: Modal Participation for the model with same floor height

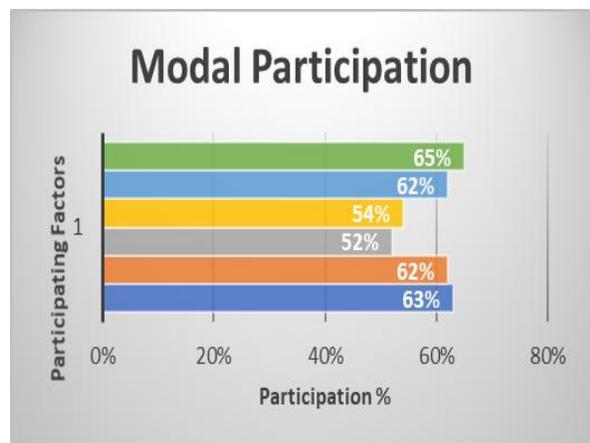| Modal participating mass ratios			
Mode	UX	UY	RZ
1	7%	54%	11%
2	62%	1%	1%
3	1%	6%	65%
4	16%	1%	1%
5	1%	15%	3%
6	1%	1%	6%
7	3%	1%	2%
8	4%	1%	6%
9	3%	2%	3%
10	1%	3%	2%
11	2%	0%	1%
12	1%	3%	1%

Chart -5: Modal Participation

3.6 Time period for modal behavior :

Table -4: Time period for modal behavior

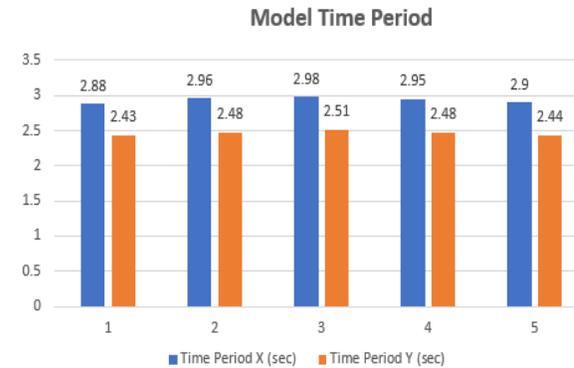| Model No.	Time Period X (sec)	Time Period Y (sec)
1	2.88	2.43
2	2.96	2.48
3	2.98	2.51
4	2.95	2.48
5	2.90	2.44

Chart -6: Time period for modal behavior

4. CONCLUSIONS

Wind analysis highlights that ground-floor height increases (NO.2) cause uniform but manageable impacts, while upper-floor modifications create dangerous stress concentrations. The 17th floor change (NO.3) shows potential for optimized load distribution in some cases, but the 24th floor alteration (NO.4) produces the most severe wind vulnerabilities, with base shear spikes up to 20% in upper floors. Drift comparisons confirm these findings, showing MODEL NO.4 exceeding acceptable limits at critical levels. This suggests that mid-to-high-rise modifications require careful wind reevaluation beyond standard code requirements.

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