

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

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Abstract—This study examines the seismic response of a 35-story vertically irregular building with varying floor heights at selected levels to simulate stiffness discontinuities. Using ETABS 2022, Response Spectrum Analysis (for seismic) is performed in accordance with IS 1893 (Part 1):2002. Results indicate that irregularities at lower and mid-levels (ground and 17th floors) significantly increase displacement, drift, 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, seismic, 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 seismic 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 seismic 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 excitation. Such irregularities compromise the uniform distribution of lateral forces, leading to stress concentrations, eccentric load paths, and amplified 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 seismic 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 seismic response. Collectively, these irregularities significantly escalate torsional demands, undermine redundancy, and necessitate stringent design considerations as mandated by seismic codes to mitigate catastrophic structural failures

2. METHODOLOGY

This study investigates the seismic 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 seismic behavior. Critical parameters such as storey displacement, inter-storey drift, base shear, natural time period, and modal mass participation were evaluated. Performance points and energy dissipation patterns were also considered to understand structural stability. The influence of stiffness discontinuities on modal characteristics, including natural periods and mode shapes, was examined in detail. Special emphasis was placed on identifying soft-storey mechanisms and their correlation with irregularity severity. 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 seismic response. Finally, it provides practical design recommendations for optimizing RCC building performance in high-seismic regions.

RCC structures (G+35) were modelled in ETABS 2022 to analyse seismic performance under 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 seismic 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 & Seismic Parameters – Specify dead, live, and seismic load cases as per IS 1893.
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 seismic 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)

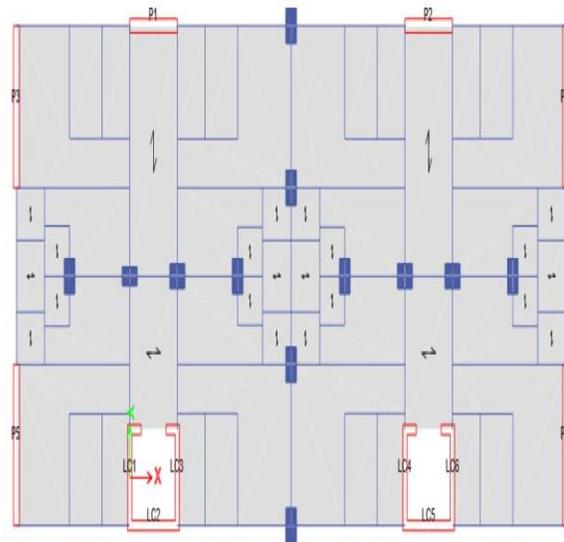


Table -1: ETABS models

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 17 th level
4	G+35	Change in floor height at 24 th level
5	G+35	Change in floor height at 35 th level

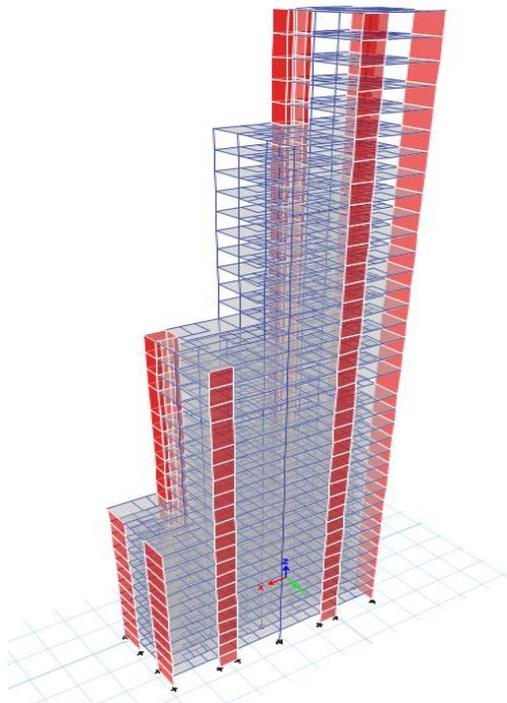


Fig -2: ETABS for G+35 structure (3D)

3. RESULT

3.1 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%

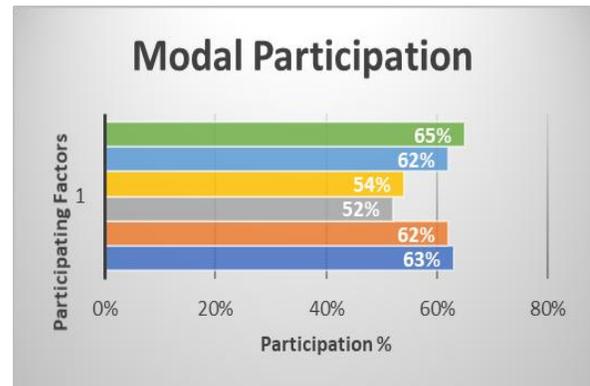


Chart -1: Modal Participation

3.2 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

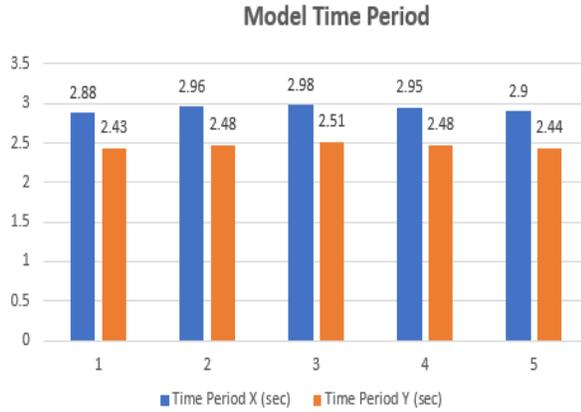


Chart -2: Time period for modal behavior

3.3 Base Shear X direction:

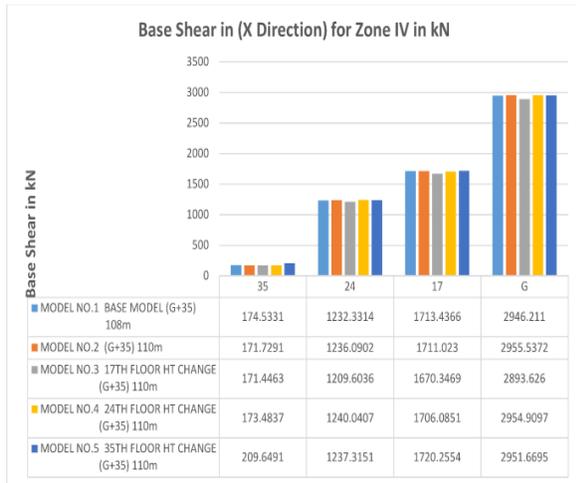


Chart -3: Base Shear X direction

3.4 Base Shear Y direction:

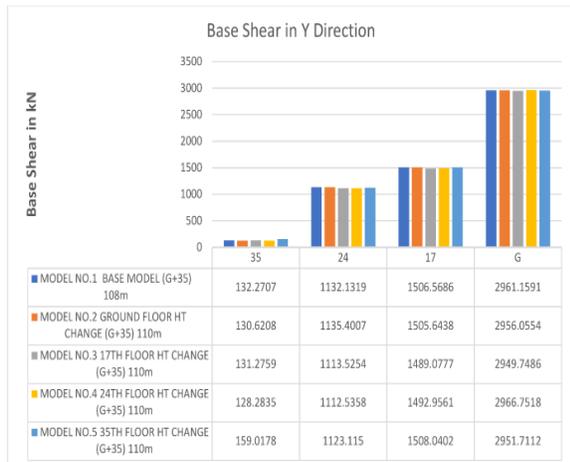


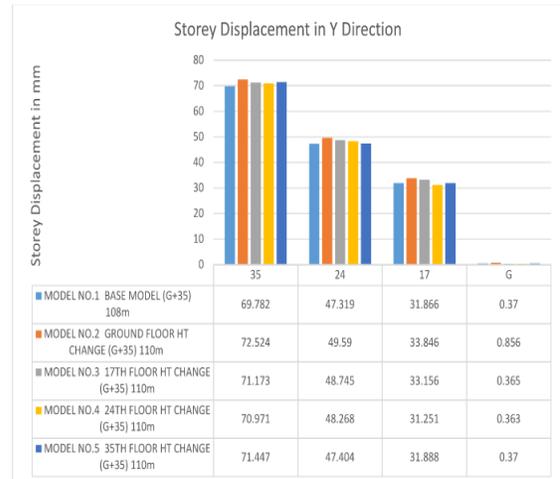
Chart -4: Base Shear Y direction

3.5 Story Displacement X direction:



Chart -5: Story Displacement X direction

3.6 Story Displacement Y direction:



4. CONCLUSIONS

Seismic 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 seismic 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 seismic reevaluation beyond standard code requirements.

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