# Seismic Analysis of High-Rise Building with Plan and Vertical Irregularity

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**Abstract -** *This research evaluates the seismic and wind performance of a 35-story reinforced concrete building characterized by significant plan and vertical irregularities. Utilizing ETABS for dynamic analysis in compliance with IS 1893:2016 and IS 16700:2017, the study assesses how geometric asymmetries such as mass-stiffness offsets and re-entrant corners amplify modal periods and torsional coupling. The findings indicate that while these irregularities increase seismic demand, structural stability and serviceability can be maintained through the strategic optimization of high-performance shear walls. Ultimately, the study demonstrates that the inherent vulnerabilities of complex high-rise architectures can be successfully mitigated by enhancing the stiffness-to-mass ratio and controlling inter-story drifts to meet stringent regulatory standards.*

***Key Words*: Seismic Analysis, High-Rise Structures, Structural Irregularity, IS 1893:2016, IS 16700:2017, Torsional Coupling**

## 1. INTRODUCTION

Modern high-rise architecture frequently prioritizes aesthetic complexity, leading to 35-story structures with significant plan and vertical irregularities—such as re-entrant corners, diaphragm discontinuities, and mass-stiffness offsets—that drastically alter dynamic signatures and increase sensitivity to non-linear seismic and wind responses. As building height scales, these asymmetries necessitate a transition to sophisticated dynamic analysis to manage torsional sensitivity and prevent localized deformations, particularly where the P-Delta effect amplifies design moments. By utilizing a high-performance shear wall system and adhering to the performance-based criteria of IS 16700:2017, this study explores the optimization of the Lateral Force Resisting System (LFRS) to ensure a stable load path and minimize eccentricities between the center of rigidity and center of mass. This research specifically investigates modal participation factors and displacement profiles, carefully detailing the interaction between primary lateral elements and gravity-only members to prevent progressive collapse. Ultimately, the study provides a robust framework for navigating the trade-off between complex architectural forms and the stringent safety requirements of contemporary Indian building codes, ensuring structural integrity under multi-directional environmental loading.

### 1.1 Plan Irregularity

In the framework of IS 1893 (Part 1): 2016, plan irregularity is defined by the non-uniform distribution of structural elements within a floor diaphragm, which disrupts predictable rigid-body action. Key manifestations include Torsional Irregularity, occurring when the maximum story drift at one end exceeds the average drift by a factor of 1.2, and Re-entrant Corners, where projections exceed 15% of the total plan dimension. Additionally, Diaphragm Discontinuities, such as large architectural cut-outs, create severe stress concentrations that impede the efficient transfer of inertial forces to vertical elements. These horizontal asymmetries create a spatial mismatch between the Center of Mass (CM) and the Center of Rigidity (CR), generating a torsional lever arm that forces the building into simultaneous translation and rotation, often leading to localized failures at the junctions of irregular wings.

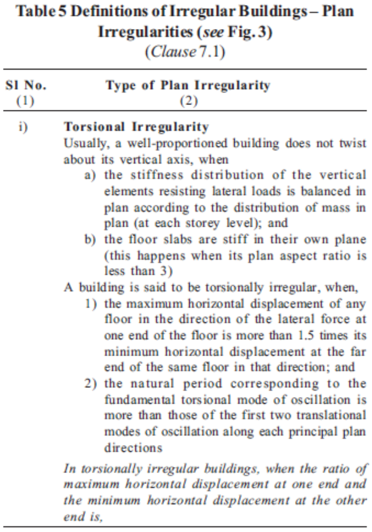


**Table 5 Definitions of Irregular Buildings – Plan Irregularities (*see* Fig. 3)**
(*Clause* 7.1)

| Sl No.<br>(1) | Type of Plan Irregularity<br>(2) |
|---|---|
| i) | **Torsional Irregularity**<br>Usually, a well-proportioned building does not twist about its vertical axis, when<br>a) the stiffness distribution of the vertical elements resisting lateral loads is balanced in plan according to the distribution of mass in plan (at each storey level); and<br>b) the floor slabs are stiff in their own plane (this happens when its plan aspect ratio is less than 3)<br>A building is said to be torsionally irregular, when,<br>1) the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction; and<br>2) the natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan directions<br>*In torsionally irregular buildings, when the ratio of maximum horizontal displacement at one end and the minimum horizontal displacement at the other end is,* |

**Fig -1**: Plan Irregularity as per IS 1893:2016

### 1.2 Vertical Irregularity

Vertical irregularity addresses abrupt changes in structural properties along a building's height, which can trigger catastrophic mechanisms like the "soft story" effect. According to IS 1893:2016, Stiffness Irregularity is identified when a story's lateral stiffness falls below 70% of the story above, while Mass Irregularity occurs if the seismic weight of a particular floor exceeds 150% of an adjacent floor. Other forms include geometric setbacks and sudden changes in the lateral force-resisting system. For high-rise structures, these discontinuities lead to a concentration of plastic hinges in a single level and amplify P-Delta effects, necessitating a robust shear wall configuration to maintain vertical load path integrity and prevent brittle failure during dynamic excitation.

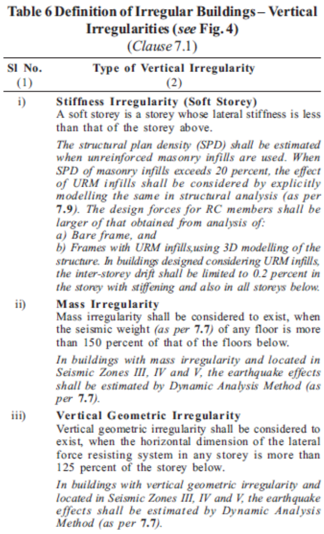


**Table 6 Definition of Irregular Buildings – Vertical Irregularities (*see* Fig. 4)**
(*Clause* 7.1)

| Sl No.<br>(1) | Type of Vertical Irregularity<br>(2) |
|---|---|
| i) | **Stiffness Irregularity (Soft Storey)**<br>A soft storey is a storey whose lateral stiffness is less than that of the storey above.<br>*The structural plan density (SPD) shall be estimated when unreinforced masonry infills are used. When SPD of masonry infills exceeds 20 percent, the effect of URM infills shall be considered by explicitly modelling the same in structural analysis (as per* **7.9***). The design forces for RC members shall be larger of that obtained from analysis of:*<br>*a) Bare frame, and*<br>*b) Frames with URM infills,using 3D modelling of the structure. In buildings designed considering URM infills, the inter-storey drift shall be limited to 0.2 percent in the storey with stiffening and also in all storeys below.* |
| ii) | **Mass Irregularity**<br>Mass irregularity shall be considered to exist, when the seismic weight *(as per* **7.7***)* of any floor is more than 150 percent of that of the floors below.<br>*In buildings with mass irregularity and located in Seismic Zones III, IV and V, the earthquake effects shall be estimated by Dynamic Analysis Method (as per* **7.7***).* |
| iii) | **Vertical Geometric Irregularity**<br>Vertical geometric irregularity shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any storey is more than 125 percent of the storey below.<br>*In buildings with vertical geometric irregularity and located in Seismic Zones III, IV and V, the earthquake effects shall be estimated by Dynamic Analysis Method (as per* **7.7***).* |

**Fig -2**: Vertical IrregulHarity as per IS 1893:2016

## 2. METHODOLOGY

The methodology for evaluating the seismic and wind performance of the 35-storied irregular structure centers on a transition from static approximations to advanced Dynamic Analysis techniques. This process begins with the development of a high-fidelity Three-Dimensional Finite Element Model (FEM). Within this computational framework, beams and columns are defined as frame elements, while shear walls and floor diaphragms are discretized as shell elements to accurately capture in-plane and out-of-plane stiffness. Material properties are assigned according to IS 456:2000, ensuring the model reflects the characteristic strengths required for high-rise construction while adhering to the structural safety mandates of IS 16700:2017.

Environmental loading is subsequently applied using a dual-track analytical approach. For seismic assessment, the Response Spectrum Method (RSM) is utilized as per IS 1893:2016 to account for the complex participation of higher-order mode shapes often triggered by plan and vertical irregularities. Simultaneously, wind load analysis is conducted according to IS 875 (Part 3), applying height-dependent pressure profiles and gust factors to evaluate dynamic oscillations. The final phase involves an iterative optimization of the Lateral Force Resisting System (LFRS), where modal periods, inter-story drifts, and torsional eccentricities are monitored to ensure the structure meets all code-defined serviceability and ductility limits.

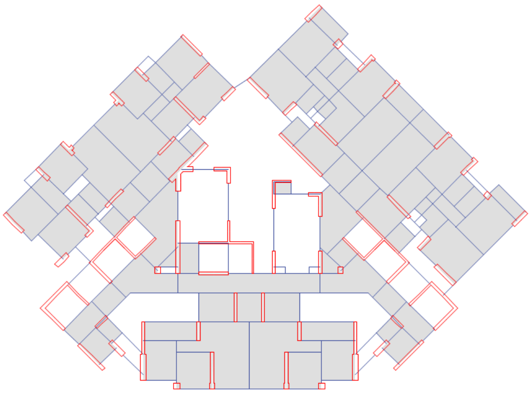


**Fig -3**: ETABS model (Plan view)

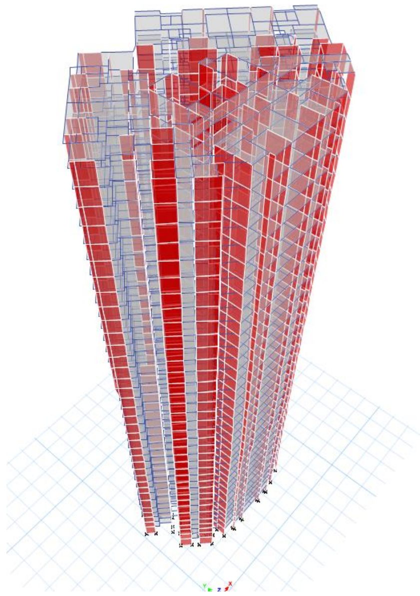


**Fig -4**: ETABS model (3D view)

**Table -1:** Structural Parameters used for modelling

| STRUCTURAL PARAMETERS | |
|---|---|
| Building Height | 116 m |
| Number of stories | 29 |
| Floor Height | 3.25 m |
| Beam Sizes | 350x700 ; 200x700 |
| Column Sizes | No Column Used |
| Slab Thickness | 125 mm,150 mm |
| SW thickness | 300 mm; 400 mm; 500 mm |

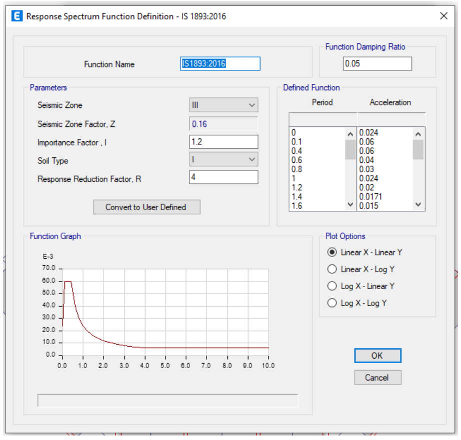
The design incorporates both area and line loads to simulate the building's gravity and superimposed dead loads SDL. Area loads vary by functional zone, with the highest SDL assigned to the Podium 5 kN/m$^2$ and Sunk areas 4.5 kN/m$^2$, while Live Loads LL are highest in residential spaces 3 kN/m$^2$.

Additionally, line loads are defined for wall partitions, specifying a significantly higher SDL for external walls 10 kN/m compared to internal walls 4kN/m, reflecting the heavier load of the building's envelope.

**Table -2:** Seismic Parameters used for modelling

| SEISMIC PARAMETERS | |
|---|---|
| Seismic zone | IV |
| Zone Factor | 0.24 |
| Site type | 2 |
| Importance factor | 1.2 |
| Time Period | 1.48 sec |

The dynamic analysis of the 35-storied irregular structure is predicated on the Response Spectrum Method (RSM), as defined within the ETABS computational environment. The input parameters are strictly synchronized with the seismic demand criteria of IS 1893 (Part 1): 2016. As illustrated in the function definition, the structure is evaluated for Seismic Zone III with a corresponding Zone Factor (Z) of 0.16, representing a moderate seismic risk area. To account for the functional criticality of the high-rise, an Importance Factor (I) of 1.2 is applied, alongside a Response Reduction Factor (R) of 4, which characterizes the ductility and energy-dissipation capacity of the lateral load-resisting system.


Response Spectrum Function Definition - IS 1893:2016

Function Name: IS1893:2016
Function Damping Ratio: 0.05

Parameters
Seismic Zone: III
Seismic Zone Factor, Z: 0.16
Importance Factor , I: 1.2
Soil Type: I
Response Reduction Factor, R: 4

Defined Function

| Period | Acceleration |
|---|---|
| 0 | 0.024 |
| 0.1 | 0.06 |
| 0.4 | 0.06 |
| 0.6 | 0.04 |
| 0.8 | 0.03 |
| 1 | 0.024 |
| 1.2 | 0.02 |
| 1.4 | 0.0171 |
| 1.6 | 0.015 |

Plot Options
● Linear X - Linear Y
○ Linear X - Log Y
○ Log X - Linear Y
○ Log X - Log Y

**Fig -5**: Response spectrum function

Mass source definition in ETABS is vital for calculating the seismic weight (W) and inertial forces according to IS 1893 (Part 1): 2016. The mass is derived from specified load patterns using code-mandated multipliers: 1.0 for Dead, SDL, and Wall loads, and scaled multipliers for Live Loads 0.25 for < = 3 kN/m² and 0.50 for > 3 kN/m². By enabling "Lump Lateral Mass at Story Levels," the model simplifies degrees of freedom to reflect rigid diaphragm action. For irregular high-rises, this precision is critical; it ensures the accurate location of the Center of Mass (CM), which directly dictates the torsional demand caused by eccentricity between the CM and Center of Rigidity (CR). Correct mass assignment ultimately ensures that modal analysis and base shear calculations reflect the structure's true dynamic behavior.

## 3. RESULT

### 3.1 Modal Participation

**Table -3:** Modal Participation

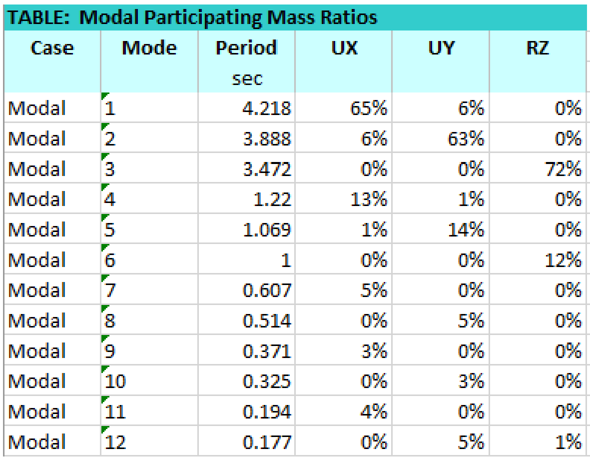


TABLE: Modal Participating Mass Ratios

| Case | Mode | Period<br>sec | UX | UY | RZ |
|---|---|---|---|---|---|
| Modal | 1 | 4.218 | 65% | 6% | 0% |
| Modal | 2 | 3.888 | 6% | 63% | 0% |
| Modal | 3 | 3.472 | 0% | 0% | 72% |
| Modal | 4 | 1.22 | 13% | 1% | 0% |
| Modal | 5 | 1.069 | 1% | 14% | 0% |
| Modal | 6 | 1 | 0% | 0% | 12% |
| Modal | 7 | 0.607 | 5% | 0% | 0% |
| Modal | 8 | 0.514 | 0% | 5% | 0% |
| Modal | 9 | 0.371 | 3% | 0% | 0% |
| Modal | 10 | 0.325 | 0% | 3% | 0% |
| Modal | 11 | 0.194 | 4% | 0% | 0% |
| Modal | 12 | 0.177 | 0% | 5% | 1% |

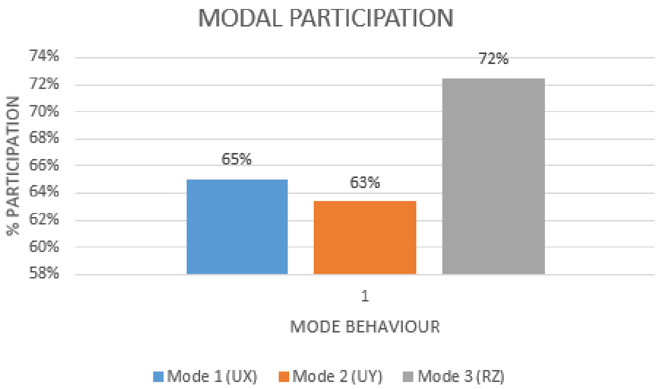


**Chart -1**: Modal Participation

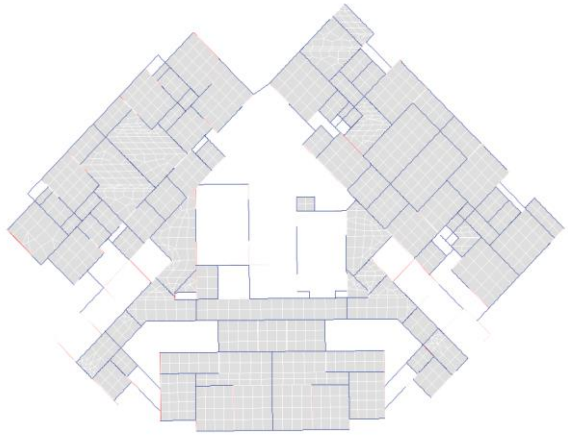


**Fig -6**: Structural Behavior in first mode (Translational)

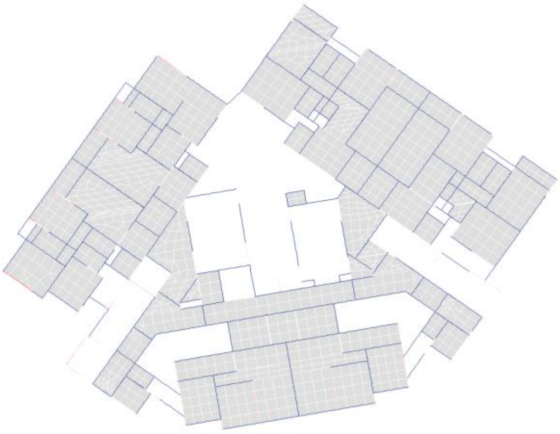
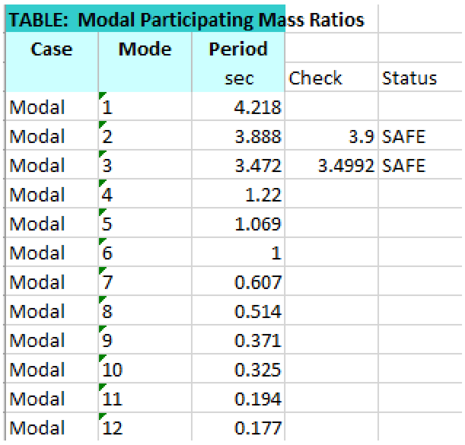


**Fig -7**: Structural Behavior in third mode (Torsional)

## 3.2 Time Period Check

**Table -4:** Time Period Check



| TABLE: Modal Participating Mass Ratios | | | | |
|---|---|---|---|---|
| Case | Mode | Period<br>sec | Check | Status |
| Modal | 1 | 4.218 | | |
| Modal | 2 | 3.888 | 3.9 | SAFE |
| Modal | 3 | 3.472 | 3.4992 | SAFE |
| Modal | 4 | 1.22 | | |
| Modal | 5 | 1.069 | | |
| Modal | 6 | 1 | | |
| Modal | 7 | 0.607 | | |
| Modal | 8 | 0.514 | | |
| Modal | 9 | 0.371 | | |
| Modal | 10 | 0.325 | | |
| Modal | 11 | 0.194 | | |
| Modal | 12 | 0.177 | | |

## 3.3 Story Displacement

**Table -5:** Time Period Check (Seismic)

| Story Displacement check (Seismic) | | | |
|---|---|---|---|
| Case | Deflection (mm) | Limit (mm) | Status |
| EQX | 180 | 464 | OK |
| EQY | 136 | 464 | OK |

**Table -6:** Time Period Check (Wind)

| Story Displacement check (Earthquake) | | | |
|---|---|---|---|
| Case | Deflection (mm) | Limit (mm) | Status |
| GWX | 135 | 232 | OK |
| GWY | 232 | 232 | OK |

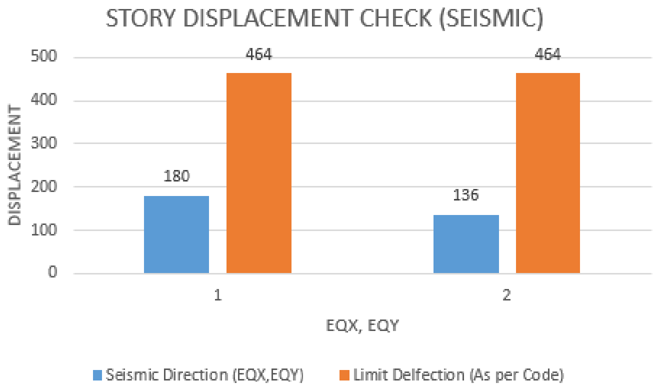


**Chart -2**: Story Displacement (Seismic)

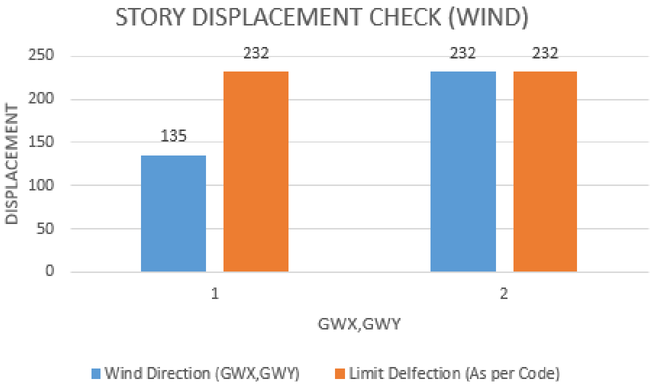


**Chart -3**: Story Displacement (Wind)

## 3.4 Story Drift

| TABLE: Story Drifts | | |
|---|---|---|
| Story | Drift | Limit (0.0004*ht) |
| F09 | 0.003047 | TRUE |
| F10 | 0.003046 | TRUE |
| F11 | 0.003039 | TRUE |
| F08 | 0.003039 | TRUE |
| F09 | 0.003026 | TRUE |
| F12 | 0.003024 | TRUE |
| F07 | 0.003023 | TRUE |
| F08 | 0.003022 | TRUE |
| F10 | 0.003021 | TRUE |
| F09 | 0.00302 | TRUE |

## 3. CONCLUSIONS

The structural performance of irregular high-rise buildings is governed by the complex interaction between geometric asymmetry and dynamic response. Plan and vertical irregularities amplify translational-torsional coupling, shifting seismic demand toward peripheral vertical elements and creating stress concentrations at re-entrant corners and setbacks. This imbalance often leads to increased inter-story drift and floor displacements, particularly where abrupt changes in stiffness occur. To ensure resilience, the design must prioritize the synchronization of the Center of Mass (CM) and Center of Rigidity (CR) through the strategic placement of shear walls, which effectively mitigates eccentricity-induced torsion. In a 35-story structure, a robust Lateral Force Resisting System (LFRS) is essential to provide the necessary redundancy and ductility to control the "whipping effect" in upper stories. Furthermore, because irregular forms are highly sensitive to higher-order mode shapes, a comprehensive dynamic analysis is required to capture the full inertial demand. Ultimately, by strictly adhering to the performance-based criteria of IS 1893:2016 and IS 16700:2017, engineers can validate complex architectural shapes, provided that displacement gradients and torsional sensitivity are managed through rigorous structural optimization.

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