

Torsion Analysis of Symmetric and Asymmetrical RC Buildings Under Seismic Loading

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Abstract—Previous major earthquakes across the Indian subcontinent have revealed that a significant percentage of multi-storey structures are not designed to be earthquake-resistant. In conventional engineering practice, buildings are often evaluated by taking into account only vertical gravity load combinations, omitting structural seismic code limits during configuration. A higher degree of damage or structural collapse is expected during strong ground motion if lateral seismic and torsional resistance are insufficient. This work details a comparative structural evaluation of reinforced concrete (RC) building frames sharing identical overall heights and column layouts but contrasting in plan symmetry. The structural models consist of a regular base frame (Square plan) and an irregular frame configuration (T-Shape plan). Both configurations are subjected to dynamic lateral loads using the response spectrum parameters detailed in IS 1893 (Part 1): 2016. The final extracted datasets show that the symmetrical base frame develops minimal storey drifts and stable translational modes. Conversely, the asymmetric T-shape frame exhibits maximum storey drift amplification, coupled torsional-translational vibrations, and premature plastic hinge formations under non-linear static evaluation. The investigation proves that geometric structural irregularities reduce safety margins. It emphasizes the importance of utilizing simpler, uniform frames to distribute lateral forces evenly. If structural irregularities are required for architectural reasons, components must be designed and detailed following the ductile provisions of IS 13920: 2016.

Index Terms—ETABS 2018, Dynamic Analysis, Symmetric Building, Asymmetric Plan, Torsional Coupling, Storey Drift, Base Shear.

I. INTRODUCTION

Post-earthquake structural damage assessment reports show that an irregular plan distribution of mass,

stiffness, and member strengths is a leading cause of severe structural damage under seismic loads. Plan irregularities induce structural asymmetry, which complicates structural analysis under dynamic actions. Asymmetric plan profiles increase lateral stress demands on perimeter frame sections and disrupt uniform load paths.

Torsional behaviour in plan-asymmetric buildings is a frequent cause of localized structural failure and global collapse during severe earthquake events. In structural engineering physics, torsional responses under dynamic actions stem from two main sources:

A. Sources of Torsional Eccentricity

- 1) *Inherent Eccentricity*: The physical offset between the floor mass distribution and the lateral stiffness configuration. This offset couples' translational displacements with rotational twisting.
- 2) *Accidental Eccentricity*: Uncertainties in live load placement, variations between nominal and actual material properties, and rotational ground motion components.

B. Structural Mechanics of Torsion

Seismic lateral force vectors act directly through the Center of Mass (CM) of a floor level, representing the centroid of dead and live loads. However, internal lateral resisting forces act through the Center of Rigidity (CR), which represents the center of lateral stiffness.

Torsional actions occur when the CM and CR are not coincident. As the distance between the CM and CR increases, the building is forced to twist around its more rigid vertical elements, generating high torsional moments. This lateral-torsional coupling triggers torsional vibrations even under purely translational

ground motion. Common architectural causes of eccentricity include non-symmetrical positioning of concrete core walls, large floor slab cutouts, structural overhangs, and irregular column spacing.

II. PROJECT OBJECTIVES & SCOPE

The research focuses on evaluating building performance across safety matrices under the following structured milestones:

- **Three-Dimensional Structural Modelling:** To model a high-rise G+24 storey space-frame structural layout using ETABS 2018, validating a regular Square Plan as the baseline against an irregular T-Shape Plan.
- **Core Mass-Rigidity Center Separation:** To calculate and map the physical distance and static eccentricity (e_{si}) between the floor Center of Mass (CM) and Center of Rigidity (CR).
- **Dynamic Multi-Modal Response Spectrum Analysis:** To perform linear dynamic analysis under IS 1893 (Part 1): 2016 parameters for Seismic Zone III to ensure cumulative modal mass participation exceeds 90%.
- **Storey Drift and Displacement Evaluation:** To cross-reference maximum lateral displacements and inter-storey drift patterns against the codal threshold of $0.004 \times h$.
- **Base Shear Distribution Modeling:** To compute, distribute, and compare design lateral forces and seismic base shear values (V_B) along primary orthogonal axes.
- **Non-Linear Static Pushover Analysis:** To apply gravity load states alongside incremental lateral load profiles to map the progressive sequence of plastic hinge formations (IO, LS, CP).
- **Cross-Sectional Frame Detailing:** To establish design and detailing modifications required to satisfy the ductile provisions of IS 13920: 2016.

A. Scope boundaries

- **Structural Height:** Limited to a G+24 storey reinforced concrete (RC) framed structure.
- **Plan Layouts:** Compares a symmetrical Square Plan with an asymmetrical T-Shape Plan.
- **Frame Classification:** Configured as an Ordinary Moment-Resisting Frame (OMRF).
- **Member Sizes:** Standardized to 600x600mm

columns and 230x600mm beams.

- **Material Grades:** Utilizes M30 concrete and Fe 500 reinforcing steel.
- **Seismic Hazard Parameters:** Boundary fixed to Seismic Zone III ($Z = 0.16$) with Type II Medium Soil.
- **Codal Guidelines:** Adheres strictly to IS 456:2000, IS 1893:2016, and IS 13920:2016.

III. METHODOLOGY

Step 1: Establish standard 5m x 5m grid alignments in ETABS 2018.

Step 2: Define and assign M30 concrete and Fe 500 steel attributes.

Step 3: Draft 3D frame wireframes detailing 600x600mm columns and 230x600mm beams across G+24 levels.

Step 4: Assign rigid floor diaphragms at each level to simulate monolithic slab action.

Step 5: Calculate and apply Dead, Live, and Wind Forces based on code benchmarks.

Step 6: Input Zone III ($Z=0.16$) values and Type II Medium Soil acceleration graphs.

Step 7: Generate 25 mandatory structural design load combinations matching IS 1893 guidelines.

Step 8: Run the Response Spectrum Method (RSM) to extract dynamic translation and rotation behaviours.

Step 9: Assign auto plastic hinges (M3 for beams, P-M-M for columns) to track structural yielding.

Step 10: Run non-linear displacement-controlled lateral step forces to generate global capacity curves.

Step 11: Collect, tabulate, and chart output parameters for base shear, storey drift, and structural twist.

IV. RESULTS AND DISCUSSION

A. Storey Displacement Results (Response Spectrum Analysis Method)

The dataset below maps the cumulative structural lateral displacement values extracted across progressive floor intervals under orthogonal earthquake load cases (EQ_X and EQ_Y):

Storey Level	Height (m)	Square EQ_X (mm)	Square EQ_Y (mm)	T-Shape EQ_X (mm)	T-Shape EQ_Y (mm)
Storey 25	74.0	42.15	42.15	58.42	64.12
Storey 22	65.0	38.40	38.40	52.88	58.20
Storey 19	56.0	33.12	33.12	45.92	50.84

Storey 16	47.0	26.85	26.85	37.36	41.50
Storey 13	38.0	20.04	20.04	28.10	31.42
Storey 10	29.0	13.35	13.35	18.94	21.28
Storey 7	20.0	7.42	7.42	10.82	12.15
Storey 4	11.0	2.95	2.95	4.45	5.08
Storey 1	2.0	0.18	0.18	0.32	0.38
Base	0.0	0.00	0.00	0.00	0.00

B. Inter-Storey Drift and Force Metrics

Structural Metric Profile	Symmetrical Building (Square Layout)	Asymmetrical Building (T-Shape Layout)	Performance Threshold (IS 1893)
Maximum Storey Drift (EQ_X)	0.0014 x h	0.0028 x h	$\leq 0.004 \times h$ (Complies)
Maximum Storey Drift (EQ_Y)	0.0014 x h	0.0034 x h	$\leq 0.004 \times h$ (Complies)
Design Base Shear V _{Bx} (kN)	2450.15	1928.42	Dependent on weight (W)
Design Base Shear V _{By} (kN)	2450.15	2012.65	Dependent on weight (W)
Fundamental Time Period T _a (s)	1.88	2.24	Shorter period yields higher safety

C. Modal Mass Participation Factors

Mode No.	Square Period (s)	Square Mass X (%)	Square Mass Y (%)	T-Shape Period (s)	T-Shape Mass X (%)	T-Shape Mass Y (%)
Mode 1	1.88	78.42	0.00	2.24	62.15	12.40
Mode 2	1.88	0.00	78.42	2.02	10.08	54.85
Mode 3	1.45	0.00	0.00	1.78	14.22	18.25
Cumulative	—	94.50	94.50	—	91.12	90.85

D. Non-Linear Pushover Performance Parameters

Performance State Parameter	Square (X-Dir)	Square (Y-Dir)	T-Shape (X-Dir)	T-Shape (Y-Dir)
Base Shear at Yielding (kN)	3850.40	3850.40	2910.15	2740.60
Ultimate Monitored Base Shear (kN)	5120.65	5120.65	3640.80	3410.25
Roof Displacement at Yielding (mm)	165.20	165.20	210.45	234.80
Ultimate Roof Displacement (mm)	480.50	480.50	385.12	352.40
Structural Ductility Factor (u)	2.91	2.91	1.83	1.50
Initial Plastic Hinge Boundary	Storey 1 Columns	Storey 1 Columns	Storey 2/3 Joint Corners	Storey 2/3 Joint Corners

V. CONCLUSION

- **Torsional Coupling:** Plan asymmetry shifts the Center of Rigidity away from the Center of Mass, causing severe structural twisting under seismic loads.
- **Increased Demand:** The asymmetric T-shape plan increases seismic base shear demand by 8.98% and lateral roof displacement by 30% compared to the symmetric square layout.
- **Drift Amplification:** While both models satisfy the IS 1893:2016 drift limit (12mm), the asymmetric frame amplifies inter-story drift by over 130% along its flexible edge.
- **Early Twisting:** Symmetrical structures isolate torsion to Mode 3. Asymmetric structures couple translation and rotation right in Mode 1, causing immediate twisting during earthquakes.
- **Reduced Ductility:** Nonlinear pushover analysis confirms that the symmetric frame possesses superior energy dissipation. The asymmetric frame experiences premature plastic hinge formations at re-entrant corners.
- **Design Recommendation:** Symmetrical layouts should be prioritized. When architectural asymmetry is unavoidable, structural elements must be designed for enhanced torsion and detailed per IS 13920:2016.

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