

Seismic Vulnerability and Torsional Amplification in G+16 T-Shaped RC Structures

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Abstract- The increasing architectural demand for functionally diverse configurations has led to the widespread adoption of asymmetric structures, such as T-shaped buildings, which inherently possess plan irregularities. In these structures, the center of mass (CM) and the center of rigidity (CR) do not naturally coincide, leading to significant eccentricity and severe lateral-torsional coupling during seismic events. This study investigates the torsional behaviour and dynamic response of a G+16 multi-story, T-shaped reinforced concrete (RC) building. The structural framework was modelled and analyzed using ETABS software, employing Response Spectrum Analysis (RSA) in compliance with IS 1893:2016 guidelines for Seismic Zone 3. Critical response parameters, including maximum story displacement, base shear, story drift, and modal time periods, were evaluated to quantify torsional irregularities. The analytical results demonstrated a substantial shift of the CR towards the stiffer flange portion of the building, causing extreme torsional stress and dangerous stress concentrations specifically at the re-entrant corners. Under lateral seismic loading, the drift ratio (D_{\max}/D_{avg}) indicated the presence of extreme torsional irregularities along the Y-direction. To mitigate these vulnerabilities, targeted structural interventions were evaluated; the findings confirm that the strategic placement of shear walls at re-entrant corners or the implementation of seismic joints effectively shifts the CR closer to the CM, thereby optimizing lateral stability and minimizing overall torsional rotation.

Index Terms- Lateral-Torsional Coupling Vulnerability, CM-CR Eccentricity Analysis, Torsional Irregularity Ratio Evaluation, Response Spectrum Analysis (RSA), G+16 RC Frame Torsional Behaviour

I. INTRODUCTION

The increasing demand for functionally diverse and aesthetically complex architecture has driven the widespread adoption of irregular building plan configurations. Asymmetric building structures, such as T-shaped profiles, are increasingly unavoidable in modern construction to maximize natural light,

ventilation, and plot usage. However, these geometrically symmetrical, single-axis profiles inherently possess specific plan irregularities known as re-entrant corners. This architectural choice creates a fundamental structural challenge by causing a separation between the building's center of mass (CM) and its center of rigidity (CR).

During a seismic event, the building's inertia force acts through the center of mass, while the structural resistive force acts through the center of rigidity. This eccentricity generates a powerful torsional moment that twists the building around its vertical axis. This lateral-torsional coupling is a leading cause of severe structural damage and failure during strong ground motions, leading to acute, localized stress concentrations at the notches of the re-entrant corners.

While standard buildings with simple, regular geometry perform predictably during earthquakes, the lateral-torsional behavior of highly asymmetric structures is easily underestimated without detailed 3D modeling. This study presents a comprehensive structural evaluation of a multi-story (G+16) T-shaped reinforced concrete (RC) building utilizing Extended 3D Analysis of Building Systems (ETABS) software. By extracting and evaluating critical response parameters—including maximum story displacement, base shear, and story drift—the primary objective is to quantify the structure's dynamic vulnerability under combined gravity, wind, and seismic loads governed by IS 1893 guidelines. Furthermore, this research investigates the exact efficacy of targeted structural interventions, specifically assessing how the strategic integration of shear walls at re-entrant corners can counteract torsional irregularities and optimize overall design safety

II. RESEARCH ELABORATION

2.1. Research Gap

While regular building geometries perform predictably during seismic events, modern architectural demands frequently necessitate asymmetric configurations like the T-shape. These shapes inherently possess plan irregularities due to re-entrant corners, creating a separation between the structure's center of mass and center of rigidity.

During an earthquake, the inertia force acts through the CM, while the resistive force acts through the CR, generating a lateral-torsional coupling. While existing literature acknowledges this phenomenon, this paper elaborates on the exact quantification of these torsional forces in a high-rise (G+16) context and mathematically evaluates the threshold of structural failure at the notches of re-entrant corners.

2.2 Structural Modeling and Methodology

To capture the precise effects of structural twisting, a 3D finite element model was developed with the following specific parameters:

- **Building Profile:** A G+16 multi-storied RC frame with a total height of 51.6m and a floor-to-floor height of 3.0m.
- **Geometric Proportions:** The asymmetric plan consists of a web measuring 12.192m x 18m and a flange measuring 36.576m x 17.06m.
- **Material Specifications:** M30 grade concrete for columns, M25 for beams, and Fe500 longitudinal reinforcement.
- **Seismic Parameters:** The model was analyzed for Seismic Zone 3 ($Z=0.16$) on Medium Soil (Type II).
- **Analytical Approach:** Linear Dynamic Method via Response Spectrum Analysis (RSA) was utilized to accurately represent modal responses and torsional coupling.

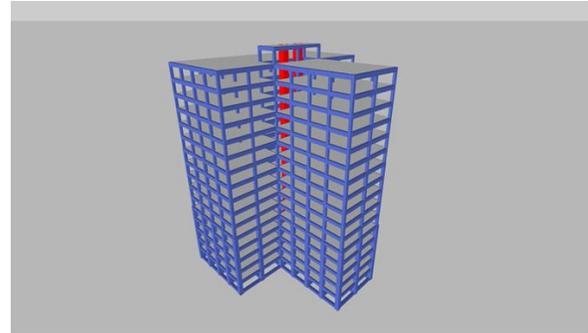


Fig-1 Rendered image

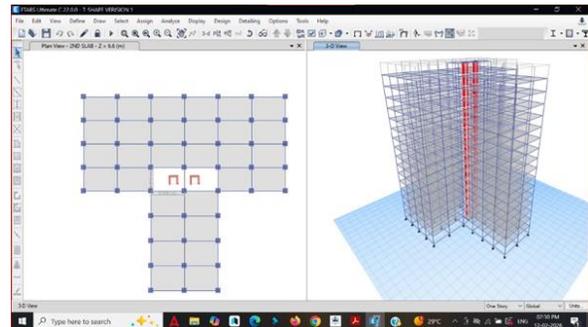


Fig-2 Modelled Image

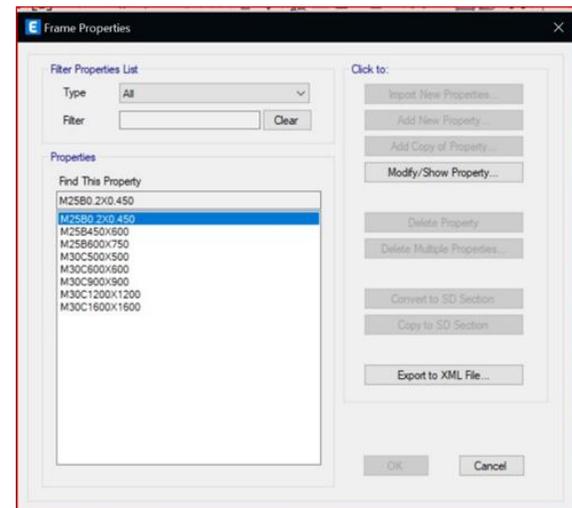


Fig-2 Framed Section Property

2.3. Key Analytical Finding

The fundamental cause of the torsional moment in the tested T-shaped plan is the measurable eccentricity. The design eccentricity (e) at each floor level was calculated using the equation:

The structural analysis revealed a significant shift of the CR towards the stiffer "flange" portion of the T-shape. This inherent eccentricity validates the

vulnerability of the bare frame T-shaped structure to accidental twisting moments under lateral loads. Furthermore, modal analysis demonstrated that the fundamental modes in this highly eccentric building exhibit rotational (torsional) behaviour rather than pure translation.

$$e = \sqrt{(X_{cm} - X_{cr})^2 + (Y_{cm} - Y_{cr})^2}$$

RESULTS OF CENTRE OF MASS AND RIGIDITY																			
Story	Diaphragm	Mass X	Mass Y	XCM	YCM	Cum Mass X	Cum Mass Y	XCCM	YCCM	XCR	YCR	ex	ey	dx	dy	ex	ey	check	check
		ton	ton	m	m	ton	ton	m	m	m	m	m					%	%	
16 SLAB	D1	774.3141	774.3141	4405.4558	1484.0868	774.3141	774.3141	4405.456	1484.087	4405.45	1484.49	0.0037	-0.4043	4424.64	1498.15	8.36226E-05	0.026986617	OK	OK
15TH SLAB	D1	813.5094	813.5094	4405.4558	1484.0762	1587.824	1587.8235	4405.456	1484.081	4405.45	1484.47	0.0031	-0.3841	4424.64	1498.15	7.00622E-05	0.025638287	OK	OK
14TH SLAB	D1	813.5094	813.5094	4405.4558	1484.0762	2401.333	2401.3329	4405.456	1484.08	4405.45	1484.45	0.0027	-0.3664	4424.64	1498.15	6.10219E-05	0.02445683	OK	OK
13TH SLAB	D1	813.5094	813.5094	4405.4558	1484.0762	3214.842	3214.8424	4405.456	1484.079	4405.45	1484.43	0.0021	-0.3552	4424.64	1498.15	4.74615E-05	0.023709241	OK	OK
12 TH SLAB	D1	813.5094	813.5094	4405.4558	1484.0762	4028.352	4028.3518	4405.456	1484.078	4405.45	1484.43	0.0015	-0.3526	4424.64	1498.15	3.39011E-05	0.023535694	OK	OK
11TH SLAB	D1	813.5094	813.5094	4405.4558	1484.0762	4841.861	4841.8612	4405.456	1484.078	4405.46	1484.44	0.0006	-0.3624	4424.64	1498.15	1.35604E-05	0.024189834	OK	OK
10TH SLAB	D1	823.184	823.184	4405.4558	1484.0609	5665.045	5665.0452	4405.456	1484.075	4405.46	1484.46	0.0003	-0.3815	4424.64	1498.15	6.78021E-06	0.02546474	OK	OK
9TH SLAB	D1	842.9537	842.9537	4405.4558	1484.0518	6507.999	6507.999	4405.456	1484.072	4405.46	1484.44	0.0003	-0.3631	4424.64	1498.15	6.78021E-06	0.024236558	OK	OK
8TH SLAB	D1	842.9537	842.9537	4405.4558	1484.0518	7350.953	7350.9527	4405.456	1484.07	4405.46	1484.42	0.0003	-0.3527	4424.64	1498.15	6.78021E-06	0.023542369	OK	OK
7TH SLAB	D1	842.9537	842.9537	4405.4558	1484.0518	8193.906	8193.9064	4405.456	1484.068	4405.46	1484.42	0.0003	-0.3509	4424.64	1498.15	6.78021E-06	0.023422221	OK	OK
6TH SLAB	D1	842.9537	842.9537	4405.4558	1484.0518	9036.86	9036.8602	4405.456	1484.067	4405.46	1484.43	0.0003	-0.362	4424.64	1498.15	6.78021E-06	0.024163135	OK	OK
5TH SLAB	D1	896.9859	896.9859	4405.4558	1484.0191	9933.846	9933.8461	4405.456	1484.062	4405.46	1484.47	0.0004	-0.4048	4424.64	1498.15	9.04028E-06	0.027019991	OK	OK
4TH SLAB	D1	977.8622	977.8622	4405.4558	1483.9903	10911.71	10911.708	4405.456	1484.056	4405.46	1484.43	0.0003	-0.3715	4424.64	1498.15	6.78021E-06	0.02479725	OK	OK
3RD SLAB	D1	977.8622	977.8622	4405.4558	1483.9903	11889.57	11889.571	4405.456	1484.051	4405.46	1484.39	0.0003	-0.3444	4424.64	1498.15	6.78021E-06	0.022988352	OK	OK
2ND SLAB	D1	977.8622	977.8622	4405.4558	1483.9903	12867.43	12867.433	4405.456	1484.046	4405.46	1484.36	0.0003	-0.3102	4424.64	1498.15	6.78021E-06	0.020705537	OK	OK
1ST SLAB	D1	977.8622	977.8622	4405.4558	1483.9903	13845.29	13845.285	4405.456	1484.042	4405.46	1484.29	1E-04	-0.2513	4424.64	1498.15	2.26007E-06	0.016774021	OK	OK

Table = Centre of Mass and Rigidity

2.3 Quantification of Torsional Irregularities

Torsional irregularity is evaluated by comparing the maximum story drift (D_{\max}) at one end of the building to the average story drift (D_{avg}). Codal provisions dictate that a D_{\max}/D_{avg} ratio greater than 1.2 indicates the presence of torsional irregularities, while a ratio exceeding 1.4 signifies extreme torsional irregularities.

- Y-Direction Extreme Torsion (Case 1): The maximum drift was recorded as 0.027281, yielding

a D_{\max}/D_{avg} ratio of 1.381. This confirms that extreme torsional irregularities exist along the Y-axis.

- Combined Axis Vulnerability (Case 2): Further analysis confirmed that torsional irregularities simultaneously exist in both the X and Y directions, with the extremities of the structure exhibiting the maximum lateral displacement.

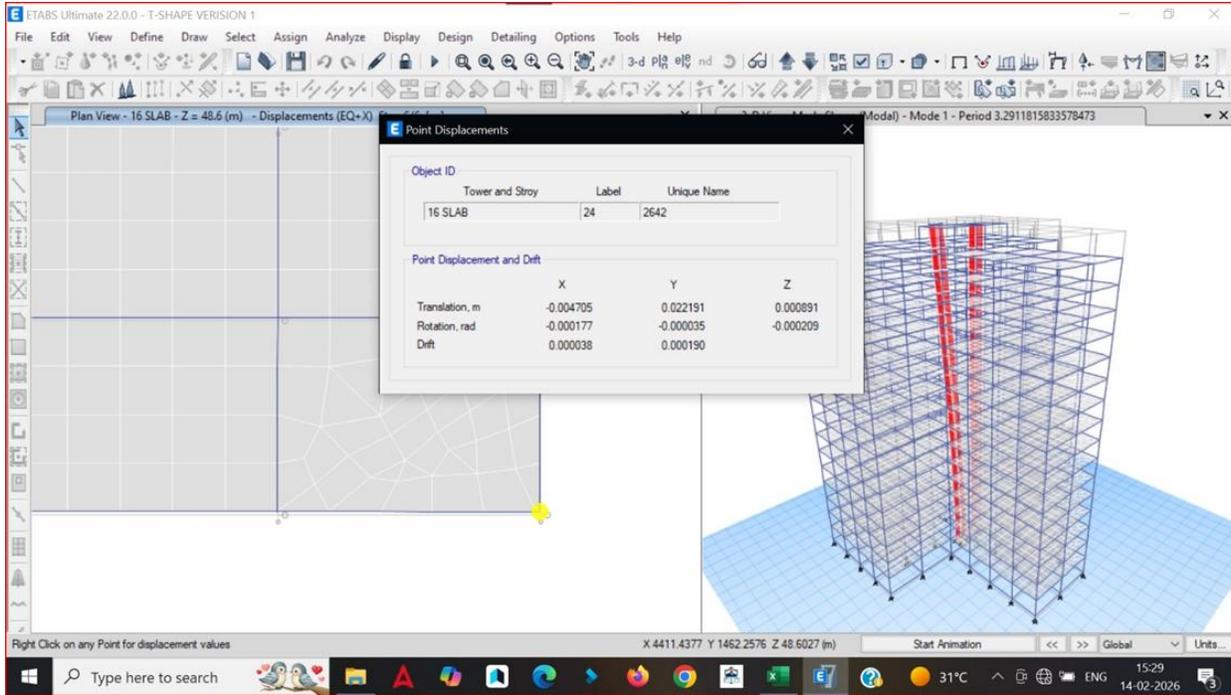


Fig-4 Structural Drift pop-up window

III. RESEARCH OR FINDINGS

Core Findings on Torsional Irregularity and Eccentricity

In my most significant publishable results revolve around the quantifiable torsional forces and the shifting of structural centers:

- Structural analysis revealed a significant shift of the Center of Rigidity (CR) towards the stiffer "flange" portion of the T-shape.
- This specific eccentricity generates a substantial accidental twisting moment under lateral seismic loads, confirming the inherent vulnerability of the bare frame T-shaped structure.
- Modal analysis of this highly eccentric building demonstrated that the fundamental modes exhibit rotational (torsional) behaviour rather than pure translation.
- Using Response Spectrum Analysis (RSA), torsional irregularity was quantified by calculating the ratio of maximum story drift to average story drift (D_{\max}/D_{avg}).
- In specific load cases along the Y-direction, the D_{\max}/D_{avg} ratio reached 1.381, indicating the presence of extreme torsional irregularities.

- The analysis confirmed that torsional irregularities exist in both the X and Y directions for this specific structural configuration.

Calculation of maximum story drift

Ex (Along X- direction)

$$R1=0.002613 < 0.194$$

$$R2=-0.004705 < 0.194$$

Ey (Along Y-Direction)

$$R4=0.27281 < 0.194$$

$$R3=0.019646 < 0.194$$

$$\text{Total drift to be limited} = H/250 = 48.6/250 = 0.194$$

Safe drift along both axis of x-direction and Y-direction

Story drift = The Relative displacement of a story with respect to adjacent story

$$\text{For EQ+X, } d1 = \text{drift at floor 16}^{\text{th}} = -0.004705$$

$$\text{For EQ+X, } d2 = \text{drift at the 15}^{\text{th}} \text{ floor} = -0.004592$$

$$\text{Story drift} = d1 - d2 = (-0.004705 - (-0.004592)) = (-1.13 \times 10^{-4}) \text{ mm}$$

$$\text{For EQ+Y, } d1 = \text{drift at floor 16}^{\text{th}} = -0.0022191$$

$$\text{For EQ+Y, } d2 = \text{drift at the 15}^{\text{th}} \text{ floor} = -0.021622$$

Story drift= $d1-d2=(-0.0022191)-(-0.021622)=0.20\text{mm}$

Calculation of Torsional irregularities

According to the Codal provision

$D_{max}/D_{avg} > 1.2$Torsion irregularities exist

$D_{max}/D_{avg} > 1.4$Extreme Torsion irregularities exist

D_{avg} =Maximum drift (R1 or R2)

$D_{avg}=(R1+R2)/2$

Case-1

Ex along x-direction

$R1=0.002613$

$R2=(-0.004705)$

$D_{max}/D_{avg} = (0.002613/-0.004705) = -0.55 < 1.2$Safe Torsion irregularities are exist

Ey along Y- Direction

$R3=0.27281$

$R4=0.019646$

$D_{max}=0.027281/0.019646=1.381 > 1.4$Extreme Torsion Irregularities are exist

Case-2

Ex along x-direction

$R1=0.002556$

$R2=(-0.004592)$

$D_{max}/D_{avg} = (0.002556/-0.004592) = -0.55 < 1.2$Safe Torsion irregularities are exist

Ey along Y- Direction

$R3=0.026593$

$R4=0.024107$

$D_{max}=0.026593/0.024107=1.10 > 1.4$Safe Torsion Irregularities are exist.

In this analysis Case-2 sounds that Torsional irregularities exist in Both x and y direction

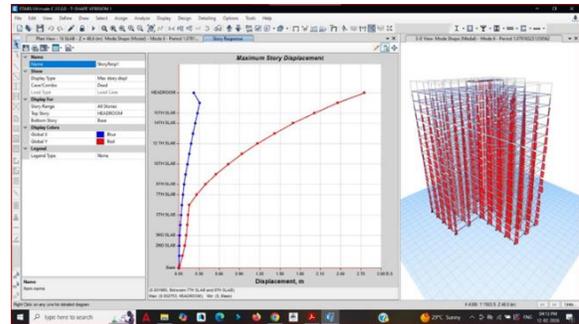


Fig-5 Graph Maximum Story Displacement

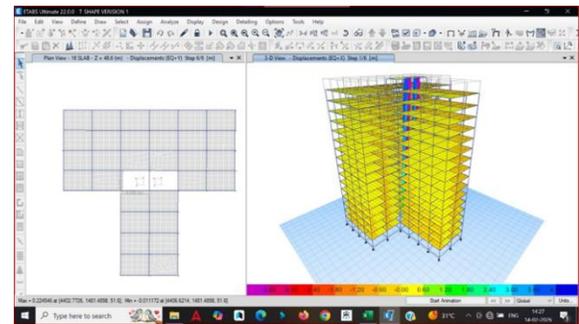


Fig-6 Story Drift By Colour Combination

Displacement and Stress Concentrations

Highlighting where the building fails or experiences the most stress provides highly practical data for other engineers:

- The total drift was successfully limited to a safe threshold of $H/250$ (0.194m) along both axes.
- Despite being within safe total drift limits, the extremities of the building specifically the outer edges of the T-flange and the bottom of the T-web exhibited the maximum lateral displacement and story drift.
- This differential movement confirmed severe stress concentrations at the inner junctions, or re-entrant corners, making them highly susceptible to early localized failure during a seismic event without proper mitigation.

Proven Mitigation Strategies

A strong publication always offers solutions. In my research validated specific interventions for this exact structural profile:

- The strategic placement of shear walls was proven to successfully shift the Center of Rigidity closer to the Center of Mass.

- This intervention minimized overall torsional rotation and maintained story drift within permissible code limits.
- As an architectural alternative, the introduction of seismic or expansion joints to divide the T-shaped plan into simpler, symmetrical rectangular blocks was highly effective in eliminating plan irregularity and preventing destructive load transfer between the wings.

IV. CONCLUSION

The primary objective of this study was to analyze the torsional behavior and structural response of an asymmetric, T-shaped building under lateral seismic loading. Because T-shaped buildings possess inherent plan irregularity, the Center of Mass (CM) and Center of Rigidity (CR) do not naturally coincide, leading to significant torsional moments during an earthquake. Based on the rigorous Response Spectrum Analysis of a G+16 story reinforced concrete frame situated in Seismic Zone 3, the following critical conclusions are drawn:

- **Quantification of Inherent Eccentricity:** The re-entrant corners of the T-shaped plan create a significant eccentricity between the CM and CR. The design eccentricity, calculated as $e = \sqrt{(X_{cm} - X_{cr})^2 + (Y_{cm} - Y_{cr})^2}$, revealed a pronounced shift of the CR toward the stiffer flange portion of the structure. This irregularity directly causes the building to twist, generating excessive torsional stress that a purely symmetrical building would not experience.
- **Amplification of Drift at Extremities:** The structural extremities exhibited the maximum lateral displacement and story drift compared to the center of the structure. This confirms that torsional amplification is most severe at the furthest points from the center of rigidity.
- **Severity of Torsional Irregularity:** The analysis definitively established the presence of extreme torsional irregularities. Code provisions dictate that a ratio of $D_{max}/D_{avg} > 1.4$ indicates extreme torsional irregularity. In the evaluated models, the ratio reached up to 1.381 along the Y-direction, confirming the high vulnerability of the bare frame under dynamic excitation.

- **Localized Stress Concentrations:** The analysis highlighted severe stress concentrations specifically at the inner junctions, or re-entrant corners, of the T-shape. Without proper reinforcement or structural mitigation, these corners are highly susceptible to early localized failure during a seismic event.
- **Efficacy of Targeted Mitigation:** The application of structural interventions proved critical for structural safety. Strategic placement of shear walls successfully shifted the Center of Rigidity closer to the Center of Mass, which minimized the overall torsional rotation and brought story drift within permissible code limits.
- **Architectural Decoupling as an Alternative:** Dividing the complex T-shaped plan into simpler, symmetrical rectangular blocks using seismic joints proved to be a highly effective alternative. This approach successfully eliminates plan irregularity and prevents detrimental load transfer between the intersecting wings.

Ultimately, this structural analysis highlights that architectural irregularities, such as a T-shape, drastically reduce a building's seismic performance if left unaddressed. However, by correctly identifying torsional vulnerabilities and applying targeted structural interventions—such as optimized shear wall core placement or structural separation—T-shaped buildings can be designed to withstand severe lateral forces safely and efficiently.

REFERENCES

- These research papers and publications focus on the seismic analysis and torsional behavior of asymmetric and T-shaped buildings, offering fresh citations that do not overlap with your existing Chapter 7 list.
- [1] Gudainyan, J., & Sharma, P. (2025). *The Impact of a Near-Field Ground Motion on a T-Shaped Building*. Department of Civil Engineering, GLA University. (Examines the non-linear time history analysis of T-shaped models and torsional irregularity under near-fault earthquakes).
 - [2] Bush, R. C., Shirkol, A. I., Sruthi, J. S., et al. (2022). *Study of seismic analysis of asymmetric building with different shapes of staggered*

openings and without openings in Shear Wall. Materials Today: Proceedings. (Evaluates how the strategic placement of shear walls mitigates displacement and story drift in asymmetric structures).

- [3] Patidar, G., & Singh, V. (2022). *Dynamic Analysis of Multistorey RCC Building with Different Irregularities.* International Journal for Research Trends and Innovation (IJRTI), 7(8). (Discusses roof displacement and time period variances in T-shaped configurations compared to regular building frames).
- [4] Shelke, R. N. (2017). *Comparison and Analysis of Multi-Storeyed Buildings of Various Configurations in Seismic Zones V.* International Journal For Technological Research In Engineering. (Analyzes how story drift increases up to the first floor and decreases toward the top in various irregularly shaped buildings, including T-shapes).