

LATERAL RESPONSE DIFFERENTIATION BETWEEN GEOMETRICALLY UNIFORM AND PLAN-DISTORTED REINFORCED CONCRETE BUILDING CONFIGURATIONS

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Abstract - Rapid urbanization has led to the widespread adoption of high-rise reinforced concrete (RC) buildings with complex architectural configurations. While geometrically uniform buildings exhibit predictable seismic behavior, plan-distorted structures such as L-, T-, and U-shaped configurations introduce significant irregularities that influence their lateral response. This study investigates the effect of plan irregularity on the seismic performance of G+20 RC buildings by conducting a comparative analysis under identical structural and loading conditions. Four models—rectangular (regular), L-shaped, T-shaped, and U-shaped—are developed and analyzed using ETABS software in accordance with IS 1893 (Part 1): 2016 provisions for Seismic Zone III. Both equivalent static and response spectrum methods are employed to evaluate key response parameters, including base shear, storey displacement, storey drift, natural period, and overturning moment. The results indicate that plan irregularity significantly affects structural behavior, particularly in terms of torsional response and force distribution. The T-shaped configuration exhibits the highest base shear and overturning moment, whereas the rectangular model shows maximum storey displacement. Among irregular configurations, the L-shaped model demonstrates relatively better performance. All models satisfy permissible drift limits; however, irregular buildings exhibit amplified torsional effects. The findings highlight the importance of considering plan configuration during seismic design and provide practical insights for improving the safety and performance of high-rise RC structures.

Keywords: Seismic response, plan irregularity, reinforced concrete buildings, storey drift, base shear, torsional effects, response spectrum analysis, high-rise structures

1. INTRODUCTION

1.1 Background

1.1.1 Urbanization and High-Rise RC Structures

Rapid urbanization, particularly in developing countries like India, has significantly increased the demand for vertical construction due to limited land availability and growing population density. Reinforced concrete (RC)

structures have emerged as the most preferred structural system for high-rise buildings because of their strength, durability, and adaptability to complex architectural forms. Multi-storey buildings such as G+20 configurations are now common in urban landscapes, necessitating a deeper understanding of their structural behavior under lateral loads, especially seismic forces (Paulay and Priestley, 1992; Chopra, 2017).

1.1.2 Use of Irregular Geometries (L, T, U Shapes)

Modern architectural practices often prioritize aesthetics and functional efficiency, leading to the adoption of irregular building configurations such as L-shaped, T-shaped, and U-shaped plans. While these geometries optimize space utilization and enhance visual appeal, they introduce discontinuities in mass and stiffness distribution. Such irregularities significantly influence the seismic response of structures by inducing eccentricity between the center of mass and center of stiffness, thereby increasing susceptibility to torsional effects (Taranath, 2016).

1.2 Problem Statement

1.2.1 Torsion and Stress Concentration in Irregular Buildings

Irregular buildings exhibit complex structural behavior under seismic loading due to non-uniform distribution of stiffness and mass. One of the most critical issues associated with plan irregularity is torsion, which arises when lateral loads do not align with the structural stiffness axis. This leads to rotational motion in addition to translational movement, increasing internal forces in structural members. Furthermore, re-entrant corners present in L-, T-, and U-shaped buildings create zones of stress concentration, making these regions highly vulnerable to damage during earthquakes (Chopra, 2017; IS 1893-1, 2016).

1.2.2 Lack of Predictable Seismic Behavior

Unlike geometrically uniform structures, irregular buildings do not follow simple and predictable patterns of load distribution. Their dynamic response is influenced by multiple interacting factors such as geometry, stiffness

variation, and modal coupling. This unpredictability complicates both analysis and design, often leading to conservative assumptions or potential underestimation of critical forces. As a result, ensuring seismic safety in such buildings remains a major challenge for structural engineers (Taranath, 2016).

2. LITERATURE REVIEW

2.1 Seismic Behavior of RC Buildings

2.1.1 Lateral Forces and Response Parameters

Reinforced concrete (RC) buildings are designed to resist both gravity and lateral loads; however, seismic forces govern the design of structures in earthquake-prone regions. These forces act predominantly in the horizontal direction and induce critical structural responses such as storey displacement, inter-storey drift, base shear, and overturning moment. Storey displacement generally increases with height and is maximum at the top level, while storey drift represents relative deformation between adjacent floors and is a key indicator of structural damage potential. Base shear reflects the total seismic force transferred to the foundation and is influenced by mass distribution and dynamic characteristics of the structure. The overall seismic performance of RC buildings depends on their ability to dissipate energy and maintain stability under these lateral demands (Chopra, 2017).

2.2 Structural Irregularity

2.2.1 Plan vs Vertical Irregularity (IS 1893 Classification)

Structural irregularity plays a significant role in influencing the seismic response of buildings. According to IS 1893 (Part 1): 2016, irregularities are broadly classified into plan and vertical types. Plan irregularity arises when there is asymmetry in the horizontal layout, leading to eccentricity between the center of mass and center of stiffness. This results in torsional effects and uneven distribution of lateral forces. Common examples include L-shaped, T-shaped, and U-shaped configurations with re-entrant corners.

Vertical irregularity, on the other hand, occurs due to discontinuities along the height of the structure, such as sudden changes in stiffness (soft storey), mass irregularity, or geometric discontinuity. These irregularities cause concentration of forces at specific levels, increasing the likelihood of structural damage. The presence of either type of irregularity complicates structural analysis and necessitates the use of advanced dynamic methods for accurate assessment (Bureau of Indian Standards, 2016).

2.3 Previous Comparative Studies

2.3.1 Regular vs Irregular Performance

Numerous studies have compared the seismic performance of regular and irregular building configurations to understand the influence of geometry on structural behavior. Regular buildings, characterized by uniform mass and stiffness distribution, tend to exhibit stable and predictable responses under seismic loading. In contrast, irregular buildings demonstrate complex dynamic behavior due to uneven stiffness and load paths, resulting in increased torsion and localized stress concentrations.

2.3.2 Reported Increase in Displacement (~50–70%)

Empirical and analytical studies have consistently reported that plan irregularity significantly amplifies lateral response parameters. In many cases, irregular configurations such as L-, T-, and U-shaped buildings exhibit 50–70% higher storey displacement compared to their regular counterparts. This increase is primarily attributed to torsional coupling and disruption in load transfer mechanisms. Additionally, irregular buildings often show higher base shear variation and drift concentration in critical zones, making them more vulnerable during seismic events (Taranath, 2016).

2.4 Research Gaps

2.4.1 Scarcity of High-Rise Studies

Despite extensive research on seismic behavior, most studies focus on low- and mid-rise buildings, with limited attention given to high-rise structures such as G+20 configurations. The dynamic behavior of tall buildings differs significantly due to increased flexibility and higher mode participation, which necessitates dedicated investigation.

2.4.2 Lack of Unified Comparative Analysis

Another major gap in existing literature is the absence of a unified comparative framework. Many researchers analyze individual irregular configurations independently, making it difficult to establish direct performance comparisons across multiple plan geometries under identical conditions.

2.4.3 Limited Indian Code-Based Studies

Although international research is abundant, there is relatively limited work based on Indian seismic codes, particularly IS 1893 (Part 1): 2016. Considering the regional variations in seismicity and construction practices, studies aligned with Indian standards are essential for practical design applications and reliable

implementation in the local context (Paulay and Priestley, 1992).

3. METHODOLOGY

3.1 Overview

3.1.1 Comparative Analytical Study

The present study adopts a comparative analytical approach to evaluate the lateral response of geometrically uniform and plan-distorted reinforced concrete (RC) buildings under seismic loading. The methodology is structured to ensure that all building models are analyzed under identical geometric, material, and loading conditions so that the variation in results can be attributed solely to differences in plan configuration. This approach enables a clear and unbiased assessment of how structural irregularity influences seismic behavior.

3.1.2 Software: ETABS

The structural modeling and analysis are carried out using ETABS (Extended Three-Dimensional Analysis of Building Systems), a widely used software for the analysis and design of multi-storey buildings. It provides advanced capabilities for modeling complex geometries, applying loads, and performing both static and dynamic analyses in accordance with relevant design codes.

3.2 Structural Models

3.2.1 Description of Building Configurations

Four different G+20 RC building models are developed to represent both regular and irregular plan configurations commonly observed in modern construction. Each model is designed with identical structural parameters to maintain consistency in comparison.

3.3 Building Specifications

3.3.1 Geometric Details of Structure

All models are considered as G+20 storey structures to represent typical high-rise buildings. The total height of the building is 63.5 meters, with uniform storey heights throughout the structure. Structural elements such as beams, columns, and slabs are designed with consistent dimensions across all models. This uniformity ensures that differences in results arise due to plan geometry rather than dimensional variations.

3.4 Material Properties

3.4.1 Concrete and Steel Grades

The material properties selected for the study reflect standard construction practices. Concrete of grade M25 is

used for all structural components, providing adequate compressive strength for high-rise construction. Reinforcement steel of grade Fe500 is adopted to ensure sufficient tensile strength and ductility. The use of uniform material properties across all models ensures a fair basis for comparison.

3.5 Loading Conditions

3.5.1 Applied Loads on Structure

The loading conditions are defined in accordance with Indian Standard provisions. Dead loads are calculated based on self-weight and other permanent structural components as per IS 875. A live load of 3 kN/m² is applied to represent typical occupancy conditions. Seismic loads are considered as per IS 1893:2016 to evaluate the response of the structure under earthquake forces. These standardized loading conditions ensure realistic and code-compliant analysis.

3.6 Seismic Parameters

3.6.1 Design Seismic Inputs

The seismic analysis is performed for Zone III, corresponding to a zone factor (Z) of 0.16. An importance factor of 1.2 is considered to account for the functional significance of the building. The response reduction factor is taken as 5, assuming a Special Moment Resisting Frame (SMRF) system with adequate ductility. These parameters are selected in accordance with IS 1893 provisions to simulate realistic seismic conditions.

3.7 Analysis Methods

3.7.1 Equivalent Static Method

The Equivalent Static Method is used to estimate seismic forces by converting dynamic effects into equivalent lateral static loads applied at different storey levels. This method is suitable for preliminary analysis and provides a simplified representation of seismic response.

3.7.2 Response Spectrum Method

The Response Spectrum Method is employed for a more accurate dynamic analysis. It considers multiple modes of vibration and captures the influence of structural properties such as mass and stiffness distribution. This method is particularly suitable for high-rise and irregular buildings, where dynamic effects play a significant role.

4. RESULTS

4.1 Base Shear Comparison

4.1.1 Variation and Percentage Difference

The base shear values obtained from seismic analysis indicate a clear variation among the different plan configurations. The T-shaped model (M3) exhibits the highest base shear, followed by the L-shaped (M2) and U-shaped (M4) models, while the rectangular model (M1) shows the lowest values. This variation is primarily due to differences in stiffness distribution and dynamic characteristics introduced by plan irregularity. A simplified comparison of peak base shear values is presented below.

Table-1: Base Shear Comparison

Model	Configuration	Relative Base Shear	% Increase (w.r.t M1)
M1	Rectangular	Lowest	0%
M2	L-shape	Higher	~10-12%
M3	T-shape	Highest	~12-15%
M4	U-shape	Moderate	~6-8%

4.2 Natural Time Period

4.2.1 Comparative Behavior

The natural time period reflects the flexibility of the structure. The rectangular model (M1) shows the highest fundamental time period, indicating greater flexibility compared to irregular configurations. In contrast, irregular models exhibit slightly lower time periods due to stiffness variations introduced by their geometry.

Table-2: Natural Time Period

Model	Configuration	Fundamental Time Period (Trend)
M1	Rectangular	Highest
M2	L-shape	Lower
M3	T-shape	Lowest
M4	U-shape	Moderate

5. CONCLUSION

This study presents a comprehensive comparative evaluation of the seismic response of geometrically uniform and plan-distorted reinforced concrete (RC) building configurations. Four G+20 models—rectangular, L-shaped, T-shaped, and U-shaped—were analyzed under identical conditions to isolate the effect of plan irregularity on lateral response. The results demonstrate that structural configuration plays a significant role in governing seismic performance.

The rectangular model, due to its uniform distribution of mass and stiffness, exhibited the highest storey displacement and drift, indicating greater flexibility. However, its behavior remained predictable and free from significant torsional effects. In contrast, irregular configurations showed comparatively lower displacement but experienced pronounced torsional response due to eccentricity between the center of mass and stiffness. Among all models, the T-shaped configuration was identified as the most critical, exhibiting the highest base shear and overturning moment, making it more vulnerable under seismic loading. The L-shaped model demonstrated relatively better performance among irregular configurations, while the U-shaped model showed moderate behavior.

All models satisfied the permissible drift limits as per codal provisions, indicating overall structural safety under the considered loading conditions. However, the amplified torsional effects in irregular buildings highlight potential risks that are not fully reflected through displacement-based parameters alone. The study emphasizes the importance of considering plan geometry in seismic design and suggests that symmetrical configurations are generally more reliable for high-rise buildings in seismic regions.

5.1. Future Scope

The present study is limited to linear elastic analysis; therefore, future research can incorporate nonlinear time history analysis to capture inelastic behavior and damage mechanisms more accurately. The inclusion of soil-structure interaction effects can further enhance the realism of the analysis. Additionally, studies can be extended to higher seismic zones (IV and V) to evaluate the performance of irregular buildings under more severe conditions. The effect of different structural systems, such as shear walls, bracings, and outrigger systems, can also be investigated to improve seismic resistance. Furthermore, optimization techniques and performance-based design approaches can be explored to develop safer and more efficient irregular structures. Experimental validation and real-time case studies would provide valuable support to analytical findings.

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