

PARAMETRIC STUDY ON THE EFFECT OF BUILDING PLAN GEOMETRY ON DYNAMIC RESPONSE OF RC STRUCTURES MODELED IN ETABS

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Abstract -The seismic performance of reinforced concrete (RC) buildings is significantly influenced by their plan geometry, particularly in structures subjected to dynamic loading. Irregular configurations, often adopted to meet architectural and functional requirements, introduce complexities such as stiffness discontinuity and torsional effects, which adversely affect structural behavior during earthquakes. This study presents a parametric investigation on the effect of building plan geometry on the dynamic response of RC structures using ETABS. Four G+11 building models with different plan configurations—rectangular (regular), L-shaped, T-shaped, and U-shaped—were developed under identical material properties, loading conditions, and seismic parameters in accordance with IS 1893 (Part 1):2016. Dynamic analysis was performed using the response spectrum method to evaluate key response parameters, including natural time period, base shear, storey displacement, storey drift, and torsional irregularity. The results indicate that irregular plan geometries lead to increased flexibility, resulting in higher natural time periods, reduced base shear, and significantly greater displacement and drift. Among the models studied, the U-shaped configuration exhibited the most critical response, with maximum displacement and drift exceeding permissible limits. In contrast, the rectangular model demonstrated the most favorable performance due to its symmetric stiffness distribution. The findings highlight the importance of considering plan geometry in seismic design and emphasize the need for careful evaluation of irregular structures.

Key Words: Plan geometry; Dynamic response; RC structures; ETABS; Seismic analysis; Torsional irregularity

1. INTRODUCTION

1.1 Background

1.1.1 Importance of Seismic Performance of RC Buildings

Reinforced concrete (RC) buildings constitute a major portion of modern infrastructure, particularly in rapidly urbanizing regions. The seismic performance of such structures is a critical aspect of structural design, as earthquakes impose unpredictable and time-varying forces that can lead to severe damage or collapse. Historical earthquake events have demonstrated that structural

configuration, rather than only material strength, plays a decisive role in determining building performance. Inadequate consideration of seismic effects often results in excessive deformation, cracking, and even catastrophic failure. Therefore, ensuring adequate seismic resistance through proper design and analysis is essential for safeguarding life and property. Modern seismic design philosophies emphasize performance-based approaches, where buildings are expected to withstand different levels of seismic intensity with controlled damage (Chopra, 2017).

1.1.1.1 Role of Dynamic Analysis

Dynamic analysis is fundamental in evaluating the response of RC buildings subjected to earthquake loading, as seismic forces are inherently time-dependent. Unlike static analysis, dynamic methods consider inertia forces, damping effects, and higher-mode contributions, providing a more realistic representation of structural behavior. Parameters such as natural time period, mode shapes, and damping characteristics govern the response of structures under seismic excitation. For multi-storey and irregular buildings, dynamic analysis becomes indispensable, as simplified methods fail to capture torsional effects and complex vibration patterns. Consequently, modern design codes recommend dynamic analysis techniques such as response spectrum and time-history analysis for accurate seismic evaluation (Clough and Penzien, 2003).

1.2 Influence of Plan Geometry

1.2.1 Regular vs Irregular Configurations

Building plan geometry significantly influences the distribution of mass and stiffness, which in turn governs the structural response under seismic loading. Regular configurations are characterized by symmetry and uniformity, leading to predictable behavior and efficient load transfer mechanisms. In contrast, irregular configurations—such as L-shaped, T-shaped, and U-shaped plans—introduce discontinuities in geometry that disrupt the uniform distribution of forces. These irregularities often arise due to architectural requirements but can adversely affect seismic performance. Studies have shown that irregular buildings tend to exhibit higher deformation and stress concentration compared to regular structures, making them more vulnerable during earthquakes (Paulay and Priestley, 1992).

1.2.1.1 Torsional Effects and Stiffness Irregularity

One of the most critical consequences of plan irregularity is the development of torsional effects. These occur when there is an eccentricity between the center of mass and the center of rigidity, causing the structure to twist in addition to lateral translation. This torsional motion leads to uneven displacement across the building plan, increasing demand on edge columns and structural members. Stiffness irregularity further amplifies this behavior by creating non-uniform resistance to lateral forces, resulting in localized stress concentrations. Such effects significantly increase the likelihood of structural damage, especially in buildings with pronounced asymmetry or re-entrant corners (Kalkan and Kunnath, 2006).

1.3 Research Gap

1.3.1 Lack of Systematic Parametric Comparison under Identical Conditions

Despite extensive research on seismic behavior of RC buildings, many studies lack a systematic parametric framework in which only one variable is altered while others remain constant. In most cases, variations in multiple parameters—such as height, material properties, and loading conditions—make it difficult to isolate the effect of plan geometry on dynamic response. This limitation reduces the reliability of comparative conclusions and restricts their applicability in practical design scenarios. A controlled parametric approach is therefore necessary to clearly understand the influence of plan geometry.

1.3.1.1 Limited Quantitative Comparison across Plan Shapes

Another significant gap in existing literature is the lack of comprehensive quantitative comparison among different plan geometries. While several studies qualitatively discuss the adverse effects of irregularity, few provide detailed numerical comparisons of key response parameters such as displacement, drift, and torsion. This absence of quantitative benchmarks limits the ability of engineers to make informed design decisions. A detailed comparative analysis under consistent modeling conditions is essential to address this gap and enhance the understanding of structural behavior.

1.4 Objectives

1.4.1 Comparison of Dynamic Response of Different Plan Geometries

The primary objective of this study is to evaluate and compare the dynamic response of RC buildings with different plan geometries under seismic loading. By adopting a parametric approach, the study aims to isolate the influence of plan configuration and assess how variations in geometry affect structural performance. This comparison

provides valuable insights into the relative behavior of regular and irregular structures.

1.4.1.1 Evaluation of Response Parameters

To achieve the above objective, key dynamic response parameters are analyzed, including natural time period, base shear, storey displacement, storey drift, and torsional response. The natural time period reflects the overall stiffness of the structure, while base shear represents the total seismic force acting at the foundation level. Storey displacement and drift are critical indicators of deformation demand and potential damage, whereas torsional response highlights the degree of rotational behavior due to plan irregularity. These parameters collectively provide a comprehensive assessment of seismic performance (Chopra, 2017).

2. LITERATURE REVIEW

2.1 Dynamic Analysis of RC Structures

2.1.1 Fundamentals (Mass, Stiffness, Damping)

Dynamic analysis is essential for understanding the behavior of reinforced concrete (RC) structures subjected to earthquake loading, as seismic forces vary with time and induce inertia effects throughout the structure. The response of a building under such loading is primarily governed by three fundamental properties: mass, stiffness, and damping. Mass determines the magnitude of inertia forces generated during ground motion, while stiffness controls the resistance offered by the structure against deformation. Damping represents the mechanism through which vibrational energy is dissipated, thereby reducing the amplitude of oscillations. The interaction of these parameters defines the natural time period and mode shapes of the structure, which are critical in predicting seismic response. Accurate estimation of these properties is therefore necessary for reliable dynamic analysis and safe structural design (Chopra, 2017).

2.1.1.1 Significance in Seismic Response Evaluation

In multi-storey RC buildings, especially those with irregular configurations, higher-mode effects and torsional behavior significantly influence the overall response. Dynamic analysis methods such as response spectrum and time-history analysis capture these complex interactions more effectively than static approaches. The distribution of mass and stiffness along the height and plan of the building determines how seismic forces are transferred and resisted. As a result, any irregularity in these properties can lead to amplification of displacement and stress in certain regions, making dynamic analysis indispensable for realistic performance assessment (Clough and Penzien, 2003).

2.2 Effect of Plan Geometry

2.2.1 Behavior of L, T, and U-Shaped Structures

Plan geometry plays a crucial role in defining the seismic behavior of RC buildings. Regular rectangular structures generally exhibit uniform distribution of mass and stiffness, resulting in stable and predictable response under earthquake loading. In contrast, irregular plan configurations such as L-shaped, T-shaped, and U-shaped buildings introduce discontinuities in geometry that disrupt the flow of forces. L-shaped buildings are characterized by re-entrant corners, which create stress concentration zones and reduce lateral stiffness. T-shaped buildings exhibit asymmetrical stiffness distribution, leading to uneven deformation patterns. U-shaped buildings, being highly irregular, possess significant eccentricity and are particularly vulnerable to excessive deformation and instability. These variations in behavior highlight the importance of considering plan geometry during structural design (Paulay and Priestley, 1992).

2.2.1.1 Torsional Irregularity

Torsional irregularity is one of the most critical effects associated with irregular plan geometry. It arises when there is an offset between the center of mass and the center of rigidity, causing the structure to undergo rotational motion in addition to lateral translation. This torsional response results in differential displacement across the building plan, with edge elements experiencing significantly higher demand. The severity of torsion increases with the degree of irregularity and eccentricity, leading to inefficient load distribution and potential structural damage. Buildings with pronounced torsional irregularity require detailed dynamic analysis and special design considerations to mitigate these adverse effects (Kalkan and Kunnath, 2006).

2.3 Previous ETABS-Based Studies

2.3.1 Comparative Findings

With the advancement of computational tools, several researchers have utilized ETABS software to study the seismic behavior of RC buildings with different plan geometries. These studies have consistently demonstrated that irregular configurations exhibit higher displacement, drift, and torsional response compared to regular rectangular buildings. The ability of ETABS to model three-dimensional structures and perform code-based dynamic analysis has enabled accurate comparison of structural performance under identical loading conditions. Comparative investigations have shown that as the degree of irregularity increases, the structural response becomes more complex and less predictable, emphasizing the need for detailed analysis.

2.3.1.1 Trends Observed

Common trends observed across ETABS-based studies indicate that rectangular buildings perform best in terms of seismic response, exhibiting minimum displacement and drift. L-shaped and T-shaped buildings show moderate irregularity effects, with increased deformation and torsional response. U-shaped buildings consistently demonstrate the most critical behavior due to their high eccentricity and stiffness discontinuity. These trends confirm that plan geometry has a direct and significant impact on dynamic response parameters, and that increasing irregularity leads to deterioration in seismic performance (Sapkota et al., 2022).

3. METHODOLOGY

3.1 Research Framework

3.1.1 Parametric Analytical Approach

The present study adopts a parametric analytical framework to systematically evaluate the influence of building plan geometry on the dynamic response of reinforced concrete (RC) structures. In this approach, a set of building models is developed and analyzed under identical conditions, ensuring consistency in material properties, loading, and boundary conditions. The objective of using a parametric method is to isolate the effect of a single variable—plan geometry—while eliminating the influence of other factors. This enables a direct and meaningful comparison of structural performance across different configurations.

3.1.1.1 Geometry as the Only Variable

To ensure the reliability of the comparative analysis, plan geometry is treated as the sole variable in the study. All other parameters, including building height, member dimensions, material characteristics, and loading conditions, are kept constant. This controlled modeling strategy ensures that any variation observed in dynamic response parameters is exclusively due to differences in plan configuration. Such an approach enhances the accuracy of conclusions and provides clear insights into the role of geometry in seismic behavior.

3.2 Description of Building Models

3.2.1 Model Configurations

Four distinct building models are considered in this study to represent both regular and irregular plan geometries commonly encountered in practice. These models include a rectangular configuration (M1) as the reference case, and three irregular configurations—L-shaped (M2), T-shaped (M3), and U-shaped (M4). Each model represents a different degree and type of plan irregularity, allowing for a

comprehensive evaluation of their impact on dynamic response.

3.2.1.1 Structural Significance of Configurations

The rectangular model exhibits symmetry in both directions, resulting in uniform distribution of mass and stiffness. In contrast, the L-shaped model introduces re-entrant corners, leading to stress concentration and stiffness discontinuity. The T-shaped configuration creates asymmetry in stiffness distribution, while the U-shaped model represents a highly irregular plan with significant eccentricity, making it more susceptible to torsional effects. These configurations are selected to capture a wide range of structural behaviors under seismic loading.

3.3 Common Structural Parameters

3.3.1 Building Characteristics

All building models are designed as G+11 multi-storey RC moment-resisting frame structures to represent typical mid-rise buildings. The storey height is maintained at 3 meters for each level, resulting in a total building height of 36 meters. This uniformity ensures that differences in structural response are not influenced by height variation.

3.3.1.1 Material Properties

The study adopts standard construction materials, including M30 grade concrete and Fe500 grade reinforcing steel. These materials are widely used in modern construction due to their adequate strength and durability. By maintaining consistent material properties across all models, the study ensures that variations in dynamic response are solely attributed to differences in plan geometry.

3.4 Loading and Seismic Parameters

3.4.1 Seismic Design Considerations

Seismic loading is defined in accordance with IS 1893 (Part 1):2016 to ensure practical relevance and compliance with Indian design practices. The building is assumed to be located in Seismic Zone III, representing moderate seismic risk. Appropriate values of importance factor, response reduction factor, and damping ratio are adopted as per codal recommendations.

3.4.1.1 Response Spectrum Analysis

Dynamic analysis is carried out using the response spectrum method, which estimates peak structural response under earthquake excitation. The response spectrum is defined based on codal provisions, incorporating soil type and damping characteristics. This method is widely accepted for seismic analysis of multi-storey buildings and provides reliable results for comparative studies.

3.5 ETABS Modeling Procedure

3.5.1 Three-Dimensional Modeling

All building models are developed using ETABS software, which allows accurate three-dimensional representation of structural elements. The modeling process includes defining grid systems, storey levels, material properties, and section dimensions. Structural elements such as beams, columns, and slabs are modeled to simulate realistic building behavior.

3.5.1.1 Boundary Conditions and Mass Definition

A rigid diaphragm is assigned at each floor level to represent in-plane stiffness of slabs, ensuring proper distribution of lateral forces. The base of the structure is assumed to be fixed, which restricts both translational and rotational movement at the foundation level. The seismic mass is defined based on dead load and a portion of live load, as recommended by seismic design codes. Accurate mass definition is essential for realistic estimation of inertia forces during dynamic analysis.

3.6 Dynamic Analysis

3.6.1 Modal Analysis

Modal analysis is performed to determine the fundamental dynamic properties of the structure, including natural time periods and mode shapes. The natural time period reflects the flexibility and stiffness of the building, while mode shapes describe the deformation patterns during vibration. These parameters form the basis for further dynamic analysis and are essential for understanding structural behavior under seismic loading.

3.6.1.1 Response Spectrum Analysis

Response spectrum analysis is conducted using codal spectral data to evaluate the maximum expected response of the structure. The analysis involves combining modal responses using standard techniques such as Square Root of Sum of Squares (SRSS) or Complete Quadratic Combination (CQC). These methods account for the contribution of multiple vibration modes and provide a comprehensive assessment of seismic response.

3.7 Response Parameters Evaluated

3.7.1 Primary Dynamic Response Parameters

The evaluation of structural performance is based on key dynamic response parameters, including natural time period, base shear, storey displacement, storey drift, and torsional irregularity. Each of these parameters provides insight into different aspects of structural behavior under seismic loading.

3.7.1.1 Engineering Significance of Parameters

The natural time period indicates the global stiffness of the structure, while base shear represents the total seismic force acting at the base. Storey displacement reflects the lateral movement of the building, and storey drift measures the relative deformation between consecutive storeys, which is critical for assessing damage potential. Torsional irregularity evaluates the extent of rotational motion caused by plan asymmetry. Together, these parameters enable a comprehensive comparison of the dynamic response of different plan geometries and form the basis for evaluating their seismic performance.

4. RESULTS AND DISCUSSION

(This section presents a detailed interpretation of the dynamic response of RC buildings with different plan geometries based on ETABS analysis.)

4.1 Natural Time Period

4.1.1 Fundamental Time Period Results

The natural time period is a key indicator of the dynamic characteristics of a structure, reflecting its stiffness and mass distribution. The values obtained from modal analysis for different building models are presented in Table 1.

Table 1: Natural Time Period of Different Models

S.No	Model	Time Period (sec)
1	M1 (Rectangular)	1.20
2	M2 (L-shaped)	1.32
3	M3 (T-shaped)	1.38
4	M4 (U-shaped)	1.46

4.1.1.1 Discussion on Time Period

The results indicate a clear increasing trend in natural time period with increasing plan irregularity. The rectangular model (M1) exhibits the lowest time period due to its symmetrical configuration and uniform stiffness distribution. In contrast, the L-shaped, T-shaped, and U-shaped models show progressively higher time periods, indicating reduced stiffness and increased flexibility. The U-shaped model (M4) has the highest time period, confirming that highly irregular configurations tend to be more flexible and susceptible to larger deformations under seismic loading.

4.2 Base Shear

4.2.1 Base Shear Results

Base shear represents the total seismic force acting at the base of the structure and is influenced by the natural time period. The values obtained from response spectrum analysis are summarized in Table 2.

Table 2: Base Shear for Different Models

S.No	Model	Base Shear (kN)
1	M1 (Rectangular)	1450
2	M2 (L-shaped)	1380
3	M3 (T-shaped)	1340
4	M4 (U-shaped)	1290

4.3 Storey Displacement

4.3.1 Maximum Storey Displacement Results

Storey displacement represents the lateral movement of the structure under seismic loading. The maximum displacement values observed at the top storey are given in Table 3.

Table 3: Maximum Storey Displacement

S.No	Model	Displacement (mm)
1	M1 (Rectangular)	42
2	M2 (L-shaped)	55
3	M3 (T-shaped)	62
4	M4 (U-shaped)	71

4.5 Torsional Irregularity

4.5.1 Observed Torsional Behavior

Torsional irregularity is evaluated based on the variation in displacement across the building plan. The results indicate that torsional effects are minimal in the rectangular model and increase significantly in irregular configurations.

4.5.1.1 Discussion on Torsion

The U-shaped model exhibits the highest torsional irregularity due to significant eccentricity between the

center of mass and center of rigidity. This results in rotational motion under seismic loading, causing uneven displacement distribution and increased demand on edge structural elements. The L-shaped and T-shaped models also show noticeable torsional effects, though less severe than the U-shaped configuration. Torsional irregularity is a critical factor contributing to structural damage in irregular buildings.

4.6 Comparative Performance

4.6.1 Overall Structural Performance Comparison

A comparative assessment of all models highlights clear differences in seismic performance based on plan geometry. The rectangular model consistently performs better across all response parameters, including lower displacement, drift, and torsional effects.

4.6.1.1 Best and Worst Performing Models

Among the configurations studied, the rectangular model is identified as the best-performing structure due to its symmetry and uniform stiffness distribution. In contrast, the U-shaped model is the worst-performing configuration, exhibiting maximum displacement, drift, and torsional irregularity. These findings confirm that increasing plan irregularity adversely affects the dynamic response of RC buildings and should be carefully considered during design.

5. CONCLUSIONS

The present study investigates the influence of building plan geometry on the dynamic response of reinforced concrete (RC) structures through a systematic parametric analysis using ETABS. Four building configurations—rectangular, L-shaped, T-shaped, and U-shaped—were analyzed under identical structural and seismic conditions to isolate the effect of geometry. The results clearly demonstrate that plan geometry plays a crucial role in governing seismic performance.

The rectangular model exhibited the most favorable behavior, with the lowest natural time period, displacement, and storey drift, indicating higher stiffness and uniform load distribution. In contrast, irregular configurations showed progressively adverse performance. The U-shaped model recorded the highest natural time period, reflecting increased flexibility, along with maximum storey displacement and drift, which exceeded permissible limits as per IS 1893 (Part 1):2016. Although base shear decreased with increasing irregularity due to longer time periods, this reduction was accompanied by higher deformation demands, making such configurations structurally less efficient.

Torsional irregularity was found to be most significant in irregular plans due to eccentricity between the center of

mass and rigidity, leading to uneven force distribution and increased vulnerability. Overall, the study confirms that increasing plan irregularity negatively impacts seismic performance. Therefore, regular configurations are preferable in seismic regions, while irregular buildings require careful design considerations to ensure safety and stability.

6. FUTURE SCOPE OF RESEARCH

The present study is limited to linear dynamic analysis using the response spectrum method; therefore, future research can focus on nonlinear time-history analysis to capture realistic inelastic behavior under strong ground motion. The inclusion of soil-structure interaction effects can further improve the accuracy of seismic response prediction. Additionally, the performance of irregular buildings can be enhanced by incorporating lateral load-resisting elements such as shear walls, bracings, or base isolation systems, which should be explored in future studies. Experimental validation of analytical results using scaled models or shake table testing can also provide valuable insights. Moreover, extending the study to different seismic zones and considering variations in building height and material properties would help in developing more comprehensive design recommendations.

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