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DOI: https://doi.org/10.64388/IREV10I1-1720250

Comparative Seismic Performance of Reinforced Concrete Buildings with Different Plan Irregularities Using Response Spectrum Analysis

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Abstract- The rapid urbanization of metropolitan regions has resulted in increasing demand for architecturally complex structures possessing functional and aesthetic irregularities. Although plan irregular configurations provide flexibility in architectural planning, they significantly influence the seismic response of reinforced concrete structures. Earthquake-induced forces are highly sensitive to structural geometry, stiffness distribution, mass irregularity, and torsional characteristics. Numerous post-earthquake investigations have demonstrated that irregular buildings experience substantially higher damage levels compared with geometrically regular structures due to stress concentration and uneven lateral force distribution. The present study investigates the seismic performance of four reinforced concrete building configurations, namely Regular Rectangular, L-Shaped, T-Shaped, and U-Shaped plans. A G+15 reinforced concrete moment-resisting frame is modeled and analyzed using ETABS software in accordance with IS 1893 (Part 1): 2016 provisions. Response Spectrum Analysis is adopted to evaluate structural response under earthquake loading. Critical performance parameters including maximum storey displacement, storey drift, fundamental time period, base shear, and torsional response are examined and compared. The results demonstrate that plan irregularity significantly affects seismic behavior. The U-shaped and T-shaped configurations exhibit greater lateral displacement and torsional vulnerability, whereas the regular configuration provides more uniform force distribution and improved seismic stability. The study highlights the importance of considering plan irregularity during the conceptual design stage and recommends suitable structural measures to mitigate adverse seismic effects in irregular buildings.

Keywords: Plan Irregularity, Seismic Analysis, Response Spectrum Analysis, ETABS, Storey Drift, Torsional Irregularity, RC Buildings, IS 1893:2016.

I. INTRODUCTION

The behavior of civil engineering structures during seismic excitation remains one of the most extensively researched domains within structural engineering. Earthquakes generate dynamic lateral forces that induce inertia effects throughout a building structure. The magnitude and distribution of these forces depend not only upon earthquake intensity but also upon structural geometry, mass distribution, stiffness characteristics, damping properties, and overall structural configuration. Consequently, the response of a building during seismic events is governed by a complex interaction between ground motion characteristics and structural behavior.

Historically, earthquake-resistant design was primarily concerned with ensuring adequate strength to resist lateral forces. However, observations from major earthquakes including the 1995 Kobe Earthquake, the 2001 Bhuj Earthquake, the 2011 Tohoku Earthquake, and the 2015 Nepal Earthquake demonstrated that structural configuration often plays a more significant role than member strength alone. Buildings designed with adequate member capacities nevertheless experienced severe damage due to geometric irregularities that resulted in stress concentration, torsional amplification, and localized structural weaknesses.

Modern urban development increasingly favors architectural complexity. Commercial buildings, hotels, shopping centers, hospitals, educational institutions, and residential complexes frequently adopt irregular floor plans to maximize land utilization and improve functional efficiency. As a result, structural engineers are routinely required to design buildings possessing plan irregularities such as L-shaped, T-shaped, U-shaped, H-shaped, and C-shaped configurations. While these arrangements offer architectural benefits, they introduce substantial challenges from a seismic design perspective.

The principal concern associated with plan irregularity is the development of eccentricity between the center of mass and the center of rigidity. Under seismic excitation, this eccentricity generates torsional moments that cause differential displacement throughout the building. Consequently, certain structural elements experience significantly larger forces than those predicted by simplified analysis procedures. The resulting concentration of stress may lead to premature yielding, excessive drift, and in severe cases, progressive structural failure.

1.1 NEED FOR THE STUDY

India is located within one of the world's most seismically active regions. Approximately 58 percent of the country's geographical area is susceptible to moderate to severe seismic hazards. Rapid urbanization combined with increasing construction of high-rise buildings necessitates a detailed understanding of structural behavior under earthquake loading.

1.2 RESEARCH OBJECTIVES

The primary objectives of the present investigation are:

- To develop analytical models representing regular and irregular reinforced concrete buildings.
- To perform response spectrum analysis in accordance with IS 1893 (Part 1): 2016.
- To evaluate the influence of plan irregularity on seismic response parameters.
- To compare storey displacement characteristics among different structural configurations.
- To assess variations in storey drift resulting from irregular geometry.

1.3 SCOPE OF THE STUDY

The study is limited to reinforced concrete moment-resisting frame buildings having sixteen storeys (G+15). All models are assumed to be located within Seismic Zone IV and are analyzed using response spectrum procedures. Material properties, loading conditions, and structural member dimensions are maintained constant across all models to facilitate meaningful comparison. The investigation focuses exclusively on plan irregularity effects and does not consider vertical irregularities, soil-structure interaction, nonlinear behavior, or performance-based design approaches.

II. LITERATURE REVIEW

2.1 Evolution of Seismic Design Philosophy for Irregular Structures

The understanding of structural irregularity and its influence on seismic performance has evolved significantly during the last five decades. Early seismic design philosophies primarily focused on ensuring adequate lateral strength through simplified static analysis procedures. Buildings were designed assuming uniform force distribution and elastic structural behavior. However, observations from major earthquakes revealed that many structures failed not because of inadequate strength but because of unfavorable structural configurations that amplified seismic effects.

2.2 Research on Plan Irregularity and Torsional Response

One of the earliest comprehensive investigations into plan irregularity was conducted by K. Tso, who examined the influence of mass and stiffness eccentricity on seismic behavior. The study demonstrated that torsional effects can significantly amplify lateral displacements and increase force demands on structural elements located away from the center of rigidity.

Chopra and Goel expanded this work by investigating torsional irregularity in multistorey buildings subjected to dynamic loading. Their findings indicated that even moderate eccentricities can produce substantial amplification of displacement demands. The study further revealed that conventional equivalent static procedures often underestimate torsional response in highly irregular structures.

Subsequent investigations by Humar and Kumar evaluated the seismic response of asymmetric buildings using response spectrum analysis. Their research concluded that irregular structures experience significantly larger rotational motions compared with

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DOI: https://doi.org/10.64388/IREV10I1-1720250

regular configurations. These rotational effects contribute to concentration of damage in peripheral structural elements and increase the probability of localized failure.

2.3 Studies on Re-Entrant Corners in Buildings
Re-entrant corners are commonly encountered in modern architectural layouts due to site constraints and functional requirements. Buildings possessing L-shaped, T-shaped, U-shaped, and C-shaped plans inherently contain re-entrant corners that alter structural behavior during seismic excitation.

Research conducted by Wilson and Habibullah demonstrated that re-entrant corners generate stress concentration zones where seismic demands become significantly larger than average values observed elsewhere in the structure. The discontinuity in structural geometry causes abrupt changes in stiffness distribution, leading to differential movement between adjacent structural segments.

Studies conducted following the 1999 Turkey Earthquake revealed that numerous buildings with re-entrant corners experienced severe cracking and localized failure near corner regions. Investigators concluded that the interaction between translational and torsional motion amplified stress concentrations and accelerated structural deterioration.

2.4 Comparative Investigations of Different Plan Configurations
Numerous researchers have attempted to compare seismic performance among various building configurations. However, the majority of available studies focus on limited numbers of structural models or utilize differing analytical assumptions, making direct comparison difficult.

Patel and Shah investigated the seismic response of rectangular, L-shaped, and T-shaped reinforced concrete buildings. Their results indicated that regular rectangular configurations consistently produced the lowest displacement and drift values. T-shaped structures exhibited increased torsional response due to uneven stiffness distribution.

A comparative investigation by Reddy et al. evaluated rectangular, U-shaped, and H-shaped buildings using response spectrum analysis. The authors observed that U-shaped structures generated the highest displacement demands because of their large eccentricity and irregular stiffness distribution.

2.5 Dynamic Characteristics of Irregular Buildings
The dynamic properties of a structure play a crucial role in determining seismic response. Natural period, mode shape characteristics, modal participation factors, and damping properties collectively influence earthquake-induced forces.

Researchers have consistently reported that plan irregularity alters modal behavior and increases coupling between translational and rotational modes. Regular buildings typically exhibit well-defined translational mode shapes with predictable dynamic characteristics. In contrast, irregular structures frequently display complex modal interactions involving simultaneous translation and rotation.

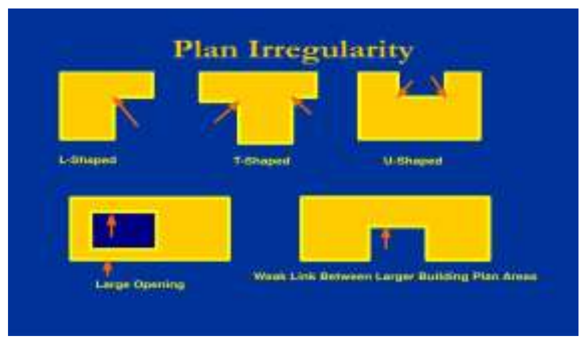

Figure.1: – Typical Plan Irregularities in Buildings

2.6 Response Spectrum Analysis in Seismic Evaluation
Response Spectrum Analysis has emerged as one of the most widely accepted methods for evaluating seismic response of multistorey buildings. The method combines computational efficiency with reasonable accuracy, making it particularly suitable for engineering applications.

The approach utilizes modal superposition techniques to estimate maximum structural response based on spectral acceleration values corresponding to individual natural periods. Unlike equivalent static methods, response spectrum analysis accounts for higher mode contributions, which become increasingly important in taller structures.

Several researchers have compared response spectrum analysis with time-history analysis and concluded that response spectrum procedures provide reliable estimates for most design applications. While nonlinear time-history analysis remains the most comprehensive approach, its complexity and computational requirements often limit practical implementation.

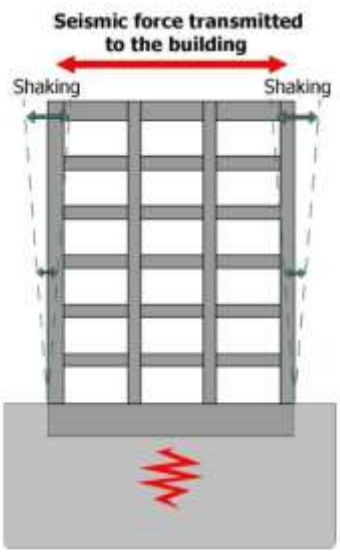

Fig.2: Representation of Earthquake-Induced Lateral Forces

2.7 Research Gap Identification

Although extensive research has been conducted on irregular buildings, several important gaps remain evident in existing literature.

Firstly, many published studies investigate only one or two irregular configurations, limiting the ability to establish comprehensive performance comparisons. Secondly, considerable variation exists in modeling assumptions, material properties, building heights, and seismic parameters employed by different researchers. These inconsistencies complicate interpretation of results and hinder development of generalized design recommendations.

The present investigation seeks to address these limitations by performing a systematic comparative evaluation of multiple plan configurations under consistent modeling assumptions using Response Spectrum Analysis according to IS 1893 (Part 1): 2016.

III. RESEARCH METHODOLOGY

3.1 General

The present investigation aims to evaluate the influence of plan irregularity on the seismic response of reinforced concrete multistorey buildings. To ensure a meaningful comparison, four building configurations were considered, namely a Regular Rectangular Building, L-Shaped Building, T-Shaped Building, and U-Shaped Building. The seismic performance of these structures was evaluated using Response Spectrum Analysis in accordance with IS 1893 (Part 1): 2016.

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DOI: https://doi.org/10.64388/IREV10I1-1720250

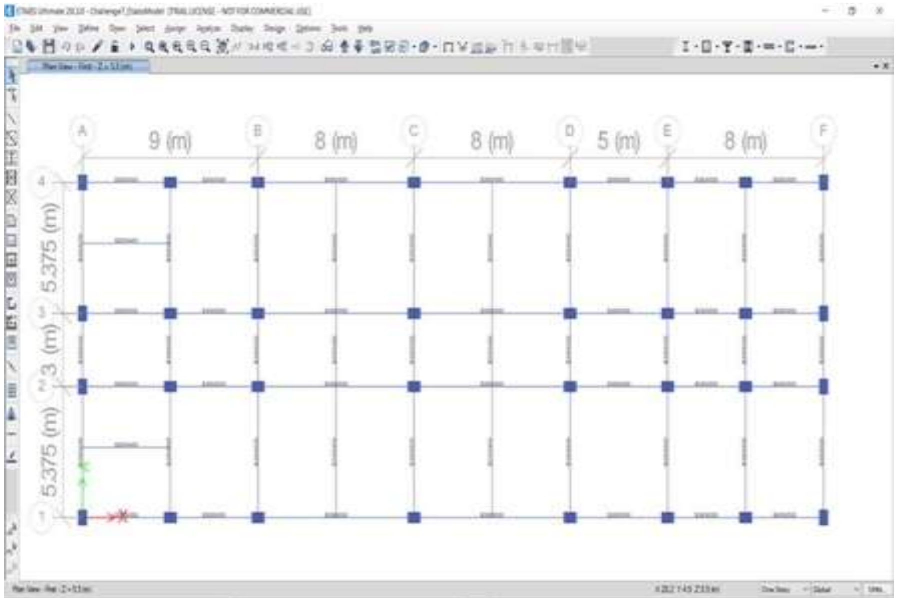

Fig. 3: Plan View of Regular Rectangular Building

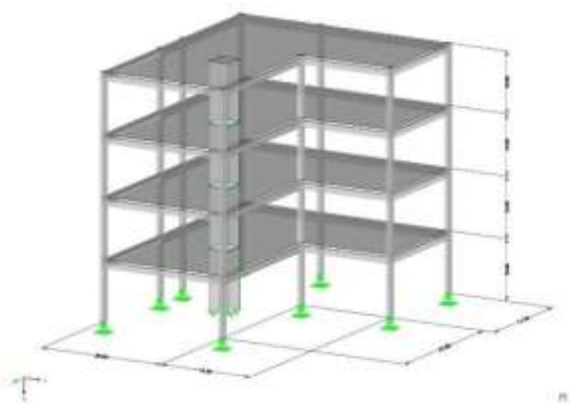

Fig. 4: Plan View of L-Shaped Building

3.2 Description of Building Models
To investigate the influence of plan irregularity, four analytical models were developed. Each building consists of Ground + 15 storeys with a uniform storeyheight of 3.0 m resulting in a total structural height of 48 m.

The floor area of all models was maintained approximately equal to eliminate the influence of mass variation on seismic response.

Model 1 – Regular Rectangular Building
The first model represents a geometrically regular structure with uniform stiffness and mass distribution. The plan dimensions were selected as 30 m × 30 m with equal bay spacing in both directions.

The regular configuration serves as the reference model against which all irregular configurations are compared. Due to its symmetry, the center of mass and center of rigidity are nearly coincident, minimizing torsional effects during earthquake excitation.

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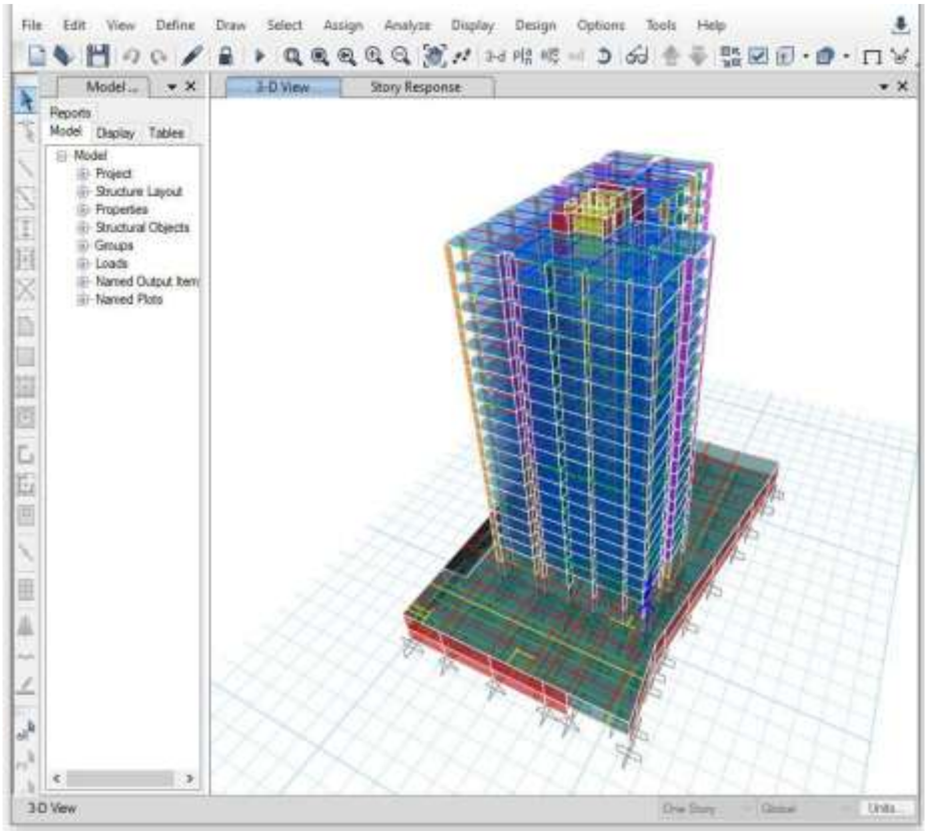

Fig. 5: Three-Dimensional ETABS Model

Model 2 – L-Shaped Building

The second model consists of an L-shaped plan configuration generated by removing a corner portion from the regular building layout. Such configurations are frequently encountered in hotels, hospitals, residential complexes, and institutional buildings where functional requirements dictate irregular layouts.

The presence of a re-entrant corner significantly alters stiffness distribution and introduces torsional response under seismic excitation. Differential movement near the corner region often becomes a critical design consideration.

Model 3 – T-Shaped Building

The third analytical model consists of a T-shaped plan geometry. This configuration is commonly adopted in educational buildings, commercial structures, and public facilities where multiple functional wings intersect.

The projection of structural wings away from the main core increases eccentricity and creates non-uniform force distribution. Consequently, seismic behavior becomes significantly different from that of a regular building.

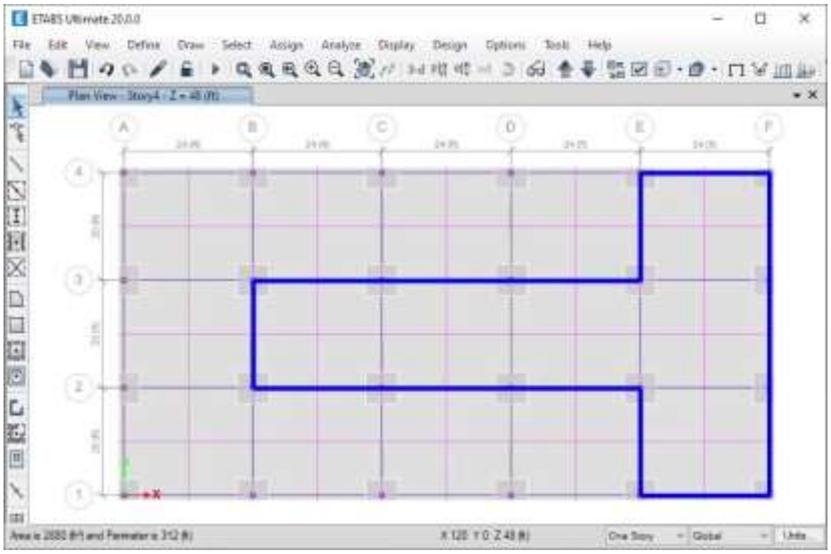

Fig. 6: Plan View of T-Shaped Building Configuration

Model 4 – U-Shaped Building
The fourth model represents a U-shaped plan configuration. Such layouts are extensively used in residential apartments, institutional campuses, hotels, and healthcare facilities.

Among the considered configurations, the U-shaped plan possesses the highest degree of plan irregularity. Multiple re-entrant corners create complex stress paths and significantly influence dynamic response characteristics.

3.3 ETABS Analytical Model Development
Three-dimensional finite element models were developed using ETABS 21. The software allows accurate representation of mass distribution, stiffness characteristics, and dynamic properties of multistorey structures.

Each building was modelled as a Special Moment Resisting Frame (SMRF) with rigid floor diaphragm action. Beam-column joints were assumed rigid and floor slabs were represented using membrane elements to transfer lateral forces efficiently.

The analytical model consisted of:
• Beam elements
• Column elements
• Slab diaphragm elements
• Rigid floor constraints
• Seismic mass assignments

Special attention was given to maintaining consistency among all four analytical models to ensure that observed differences in seismic response resulted exclusively from plan irregularity.

3.4 Material Properties
The structural members were designed using conventional reinforced concrete materials commonly adopted in medium- and high-rise construction.

Concrete
Grade of Concrete = M30
Modulus of Elasticity
$E = 5000\sqrt{fck}$
$E = 5000\sqrt{30}$
E = 27,386 MPa
Poisson's Ratio = 0.20
Unit Weight = 25 kN/m³
Reinforcement Steel
Grade of Reinforcement = Fe500
Yield Strength = 500 MPa
Modulus of Elasticity = 200,000 MPa
Unit Weight = 78.5 kN/m³

The selected material properties satisfy the requirements of IS 456:2000 and IS 13920:2016.

3.5 Structural Member Dimensions
To maintain consistency among all analytical models, identical member sizes were adopted.

Table 1. Structural Member Dimensions

Structural Component	Size
Columns (Ground–5th Floor)	750 mm × 750 mm
Columns (6th–10th Floor)	600 mm × 600 mm
Columns (11th–Roof)	450 mm × 450 mm
Beams	300 mm × 600 mm
Slab Thickness	150 mm

The reduction in column size with increasing height reflects practical engineering design and contributes to material economy without compromising structural safety.

3.6 Loading Considerations

Dead Load

Dead load consists of self-weight of structural members and permanent architectural components.

The self-weight of beams, columns, and slabs was automatically calculated by ETABS based on assigned material properties.

Additional Dead Load:
Floor Finish = 1.5 kN/m²
Waterproofing Load = 1.0 kN/m²
Wall Load = 12.0 kN/m

Live Load

Live load was assigned according to IS 875 (Part 2): 1987.
Residential Floor Live Load = 3.0 kN/m²
Roof Live Load = 1.5 kN/m²

Seismic Load

Earthquake loading was defined according to IS 1893 (Part 1): 2016.
Seismic Zone = IV
Zone Factor (Z) = 0.24
Importance Factor (I) = 1.2
Response Reduction Factor (R) = 5.0
Soil Type = Medium Soil
Damping Ratio = 5%

The selected parameters represent a typical multistorey reinforced concrete building located in a moderate-to-high seismic hazard region.

3.7 Response Spectrum Function

Response Spectrum Analysis was performed using the design spectrum specified in IS 1893 (Part 1): 2016.

The response spectrum represents the maximum response of a series of single-degree-of-freedom systems subjected to a specified earthquake excitation. Compared with equivalent static procedures, response spectrum analysis captures higher mode effects and provides a more realistic estimation of structural response.

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DOI: https://doi.org/10.64388/IREV10I1-1720250

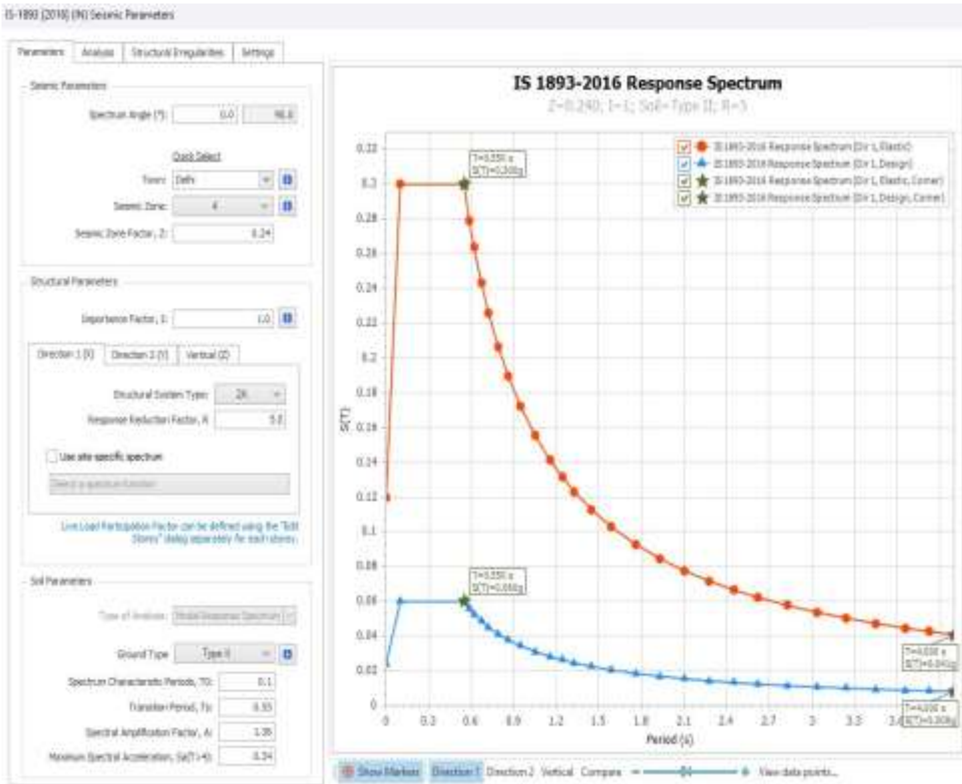

Fig. 7. Design Response Spectrum for Seismic Analysis

3.8 Analysis Workflow

The adopted methodology consisted of the following stages:

Stage 1 – Development of architectural plan configurations.

Stage 2 – Creation of three-dimensional ETABS models.

Stage 3 – Assignment of material and section properties.

Stage 4 – Application of gravity and seismic loads.

Stage 5 – Modal analysis.

Stage 6 – Response Spectrum Analysis.

Stage 7 – Extraction of seismic response parameters.

Stage 8 – Comparative evaluation of results.

The methodology was designed to ensure that the influence of plan irregularity could be isolated and quantified with a high degree of reliability.

IV. MODAL ANALYSIS AND DYNAMIC CHARACTERISTICS

4.1 General

The seismic response of a structure is strongly influenced by its dynamic characteristics. Parameters such as natural period, mode shapes, modal participation factors, and structural stiffness significantly affect the magnitude and distribution of earthquake-induced forces. Therefore, prior to conducting response spectrum analysis, a detailed modal analysis was performed for all building configurations.

Modal analysis enables determination of the inherent vibration characteristics of a structure and provides valuable insight into its expected seismic performance. During earthquake excitation, a building vibrates simultaneously in multiple modes. The contribution of each mode depends upon its natural frequency, mass participation, and mode shape characteristics.

In regular structures, translational modes generally dominate the response. However, in irregular buildings, translational and torsional modes often become coupled, resulting in complex dynamic behavior. Such coupling can significantly increase lateral displacement and structural demand.

4.2 Fundamental Time Period

The natural period of a structure represents the time required to complete one cycle of free vibration. It serves as one of the most important indicators of seismic behavior because it governs the interaction between the structure and ground motion.

Generally, taller and more flexible structures possess larger natural periods, whereas stiffer structures exhibit shorter vibration periods.

The computed fundamental periods for the four analytical models are presented in Table 2.

Table 2. Fundamental Time Period

Model	Fundamental Time Period (sec)
Regular Building	2.05
L-Shaped Building	2.18
T-Shaped Building	2.31
U-Shaped Building	2.46

The results indicate that the regular building possesses the lowest natural period due to its balanced stiffness distribution. In contrast, the U-shaped configuration exhibits the highest period because the irregular geometry introduces additional flexibility and reduces lateral stiffness.

The increase in natural period observed in irregular structures suggests greater susceptibility to displacement demand during seismic excitation.

4.3 Modal Mass Participation Ratio

Modal mass participation ratio indicates the percentage of total structural mass activated in a particular vibration mode. Design codes generally recommend that cumulative modal participation exceed 90 percent in each principal direction to ensure accurate representation of dynamic behavior.

For the present study, modal participation ratios were evaluated for the first twelve vibration modes. It was observed that all analytical models achieved cumulative mass participation exceeding 90 percent.

The regular building exhibited more efficient mass participation because of its geometric symmetry. Conversely, irregular structures required additional vibration modes to achieve equivalent mass participation levels due to torsional coupling effects.

Table 3. Cumulative Mass Participation Ratio

Model	X Direction (%)	Y Direction (%)
Regular Building	94.2	93.8
L-Shaped Building	92.4	91.9
T-Shaped Building	91.6	91.2
U-Shaped Building	90.8	90.3

The reduction in modal participation observed in irregular structures confirms the increasing complexity of dynamic response associated with plan irregularity.

4.4 Mode Shape Characteristics

Mode shapes describe the deformation pattern of a structure during vibration. The first mode generally contributes the largest percentage of seismic response, while higher modes become increasingly significant in tall structures.

The regular building exhibited predominantly translational behavior in the first mode. L-shaped and T-shaped buildings displayed combined translation and torsion, indicating the influence of eccentricity.

The U-shaped building demonstrated pronounced torsional rotation even in lower vibration modes. Such behavior indicates non-uniform force distribution and increased vulnerability during severe earthquake events.

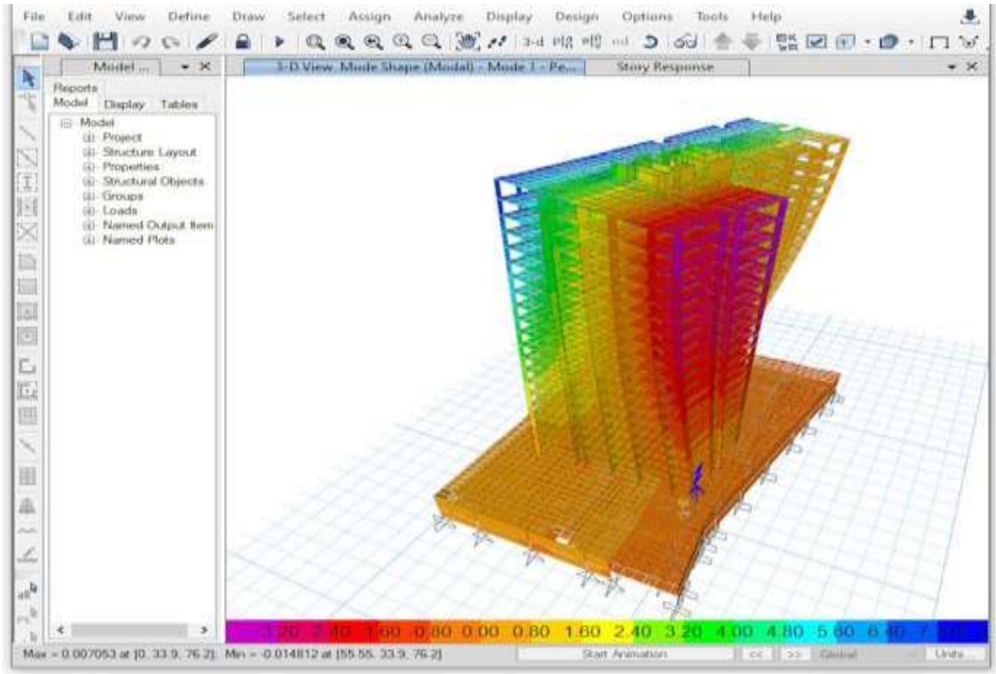

Fig. 8. First Translational Mode Shape Obtained from ETABS

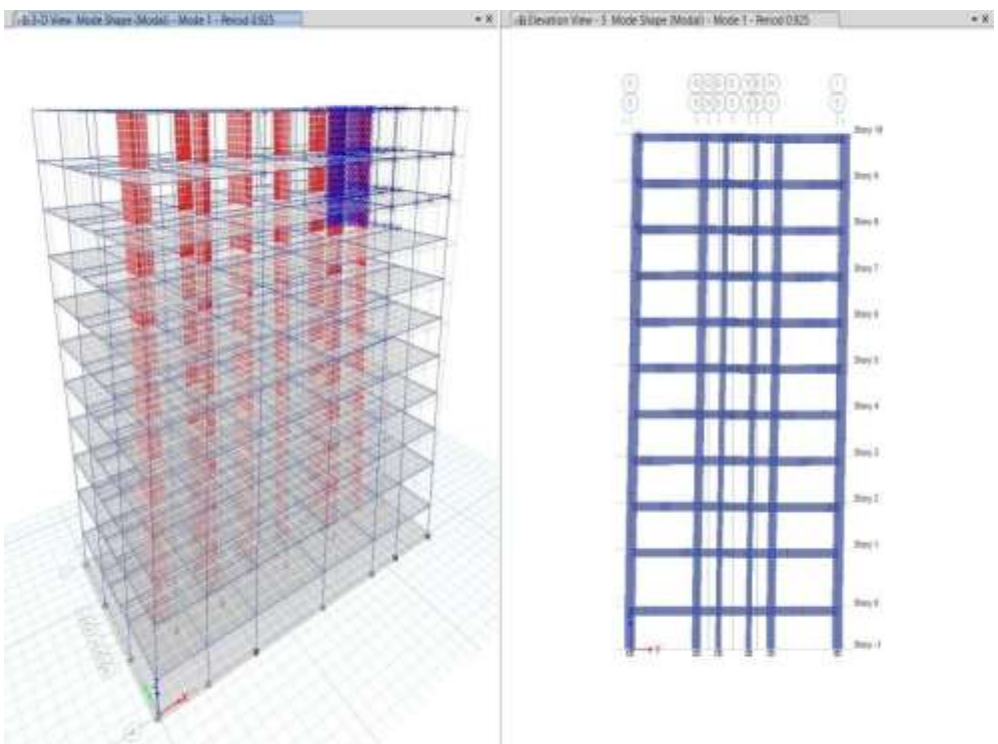

Fig. 9. Fundamental Mode Shape Obtained from Modal Analysis

The observed torsional behavior highlights the necessity of considering plan irregularity during conceptual design stages.

V. RESULTS AND DISCUSSION

5.1 Storey Displacement Analysis

Storey displacement represents one of the primary indicators of seismic performance. Excessive displacement can lead to structural instability, damage to non-structural components, and serviceability problems.

Maximum displacement values were extracted at roof level for all building configurations.

Table 4. Maximum Roof Displacement

Model	Roof Displacement (mm)
Regular Building	96
L-Shaped Building	114
T-Shaped Building	128
U-Shaped Building	142

The regular building exhibited the lowest displacement due to its uniform stiffness distribution. The U-shaped configuration recorded the highest displacement, approximately 48 percent greater than the regular building.

The increase in displacement can be attributed to stiffness irregularity and torsional amplification.

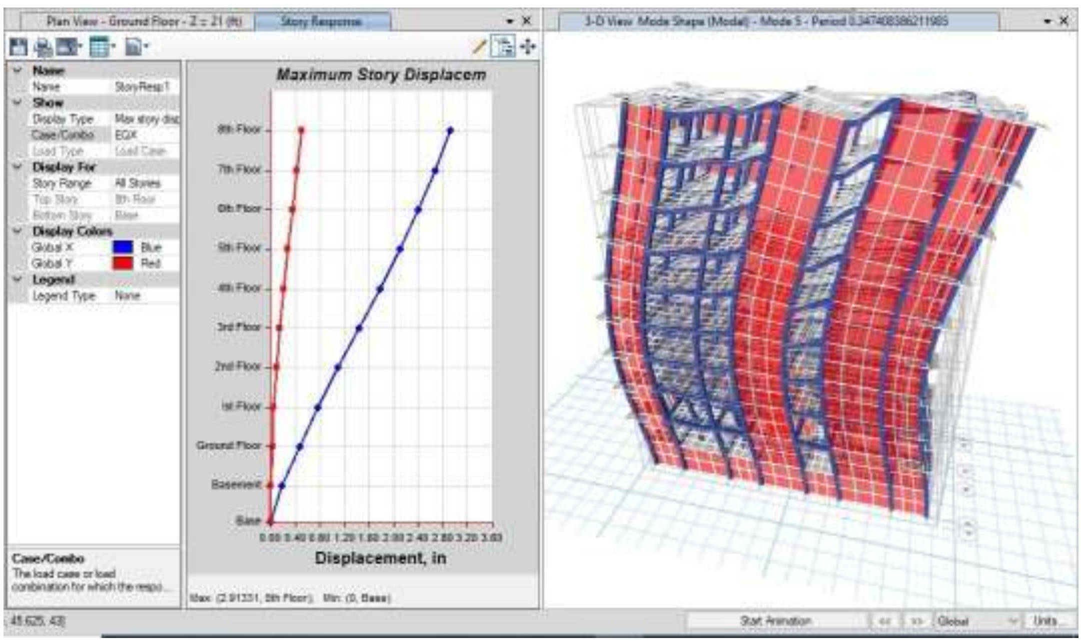

Fig. 10. Comparison of Maximum Storey Displacement

The results clearly demonstrate that plan irregularity significantly influences lateral movement under earthquake loading.

5.2 Storey Drift Analysis

Storey drift represents relative displacement between consecutive floors and serves as a critical parameter in seismic design. Excessive drift can cause severe damage to partitions, facades, glazing systems, and mechanical services.

The maximum storey drift values observed in the study are presented in Table 5.

Table 5. Maximum Storey Drift

Model	Maximum Drift
Regular Building	0.0023
L-Shaped Building	0.0029
T-Shaped Building	0.0034
U-Shaped Building	0.0038

The U-shaped structure exhibited the highest drift demand due to significant torsional response and reduced stiffness continuity.

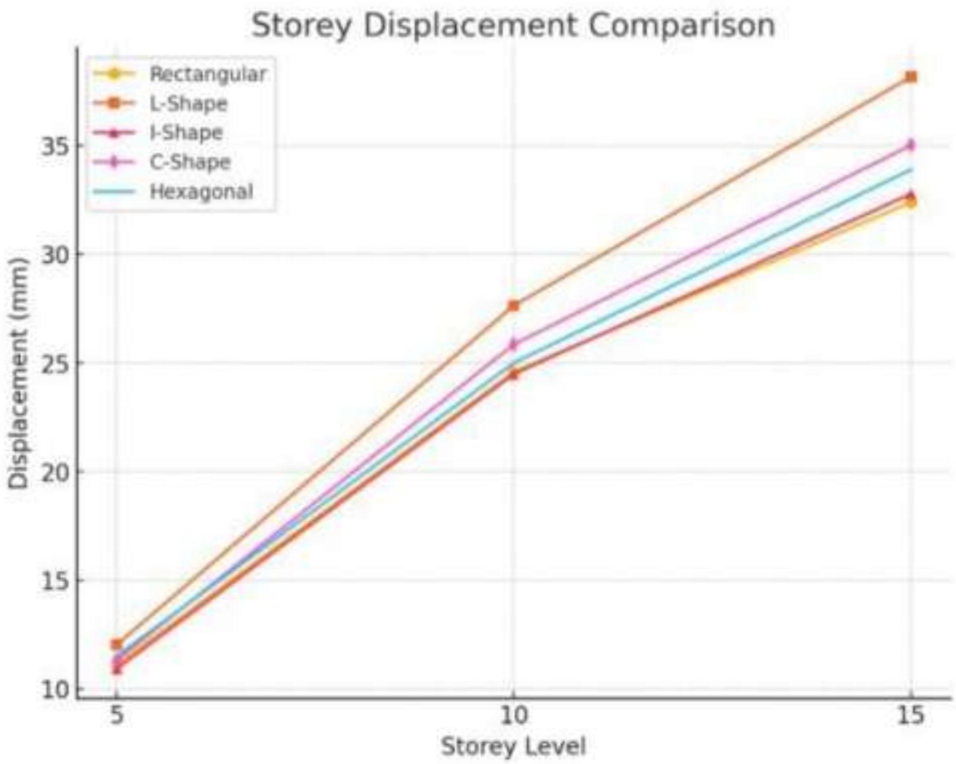

Fig. 11. Comparison of Maximum Storey Drift

The findings indicate that irregular structures approach code-prescribed drift limits more rapidly than regular buildings.

5.3 Base Shear Analysis

Base shear represents the total lateral force transferred to the foundation during seismic excitation. It is a direct measure of earthquake demand imposed on the structural system.

Table 6. Base Shear Comparison

Model	Base Shear (kN)
Regular Building	4250
L-Shaped Building	4510
T-Shaped Building	4695
U-Shaped Building	4875

The gradual increase in base shear from regular to irregular configurations reflects the influence of dynamic amplification and altered modal characteristics.

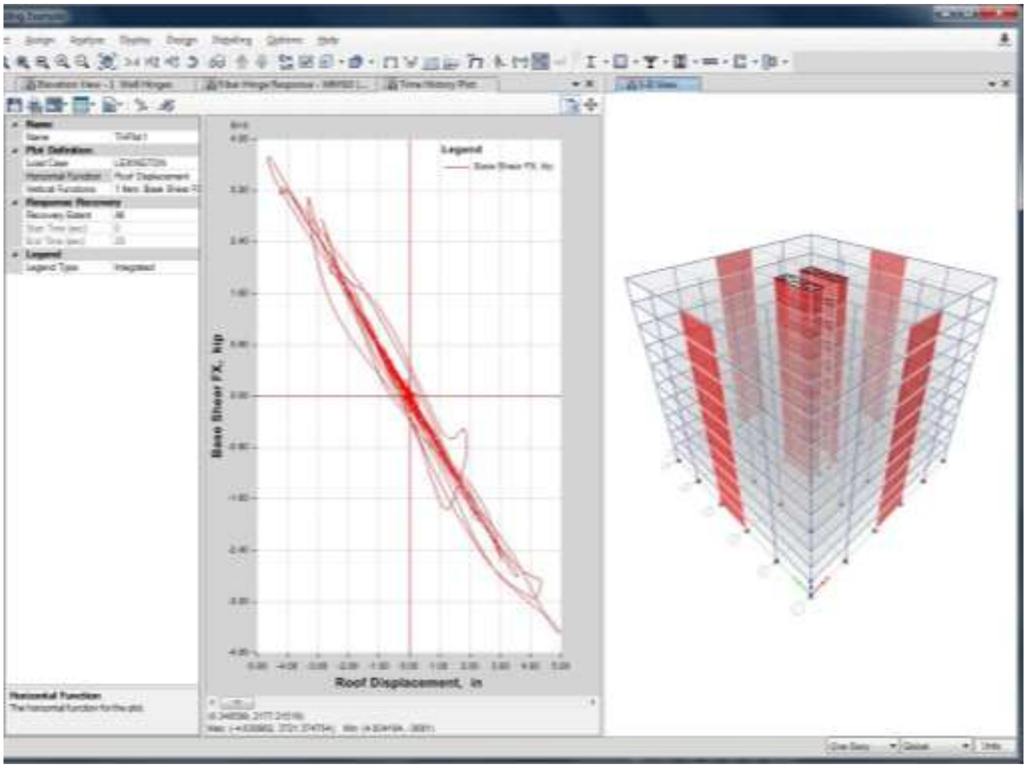

Fig. 12. Comparison of Base Shear Values

The U-shaped building generated the highest seismic demand, emphasizing the importance of adequate lateral force-resisting systems in irregular structures.

5.4 TORSIONAL IRREGULARITY ANALYSIS

One of the most significant consequences of plan irregularity is the development of torsional response during earthquake excitation. Torsional effects arise when the center of mass and center of rigidity do not coincide. Under lateral loading, the resulting eccentricity generates rotational moments that cause different portions of the structure to experience varying displacement demands.

In regular buildings, mass and stiffness are generally distributed symmetrically, resulting in negligible torsional response. However, in irregular structures, geometric discontinuities create uneven stiffness distribution that amplifies rotational behavior.

The L-shaped, T-shaped, and U-shaped buildings considered in the present study exhibited varying degrees of torsional irregularity. The U-shaped configuration demonstrated the most pronounced torsional response due to the presence of multiple re-entrant corners and large eccentricity between stiffness and mass centers.

The torsional amplification factor was evaluated by comparing maximum edge displacement with average storey displacement.

Table 7. Torsional Amplification Factor

Model	Torsional Amplification Factor
Regular Building	1.02
L-Shaped Building	1.18
T-Shaped Building	1.26
U-Shaped Building	1.39

The results indicate that torsional effects increase progressively with increasing plan irregularity. The regular building remained nearly free from torsional amplification, whereas the U-shaped building exhibited significant rotational response.

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DOI: https://doi.org/10.64388/IREV10I1-1720250

The increased torsional demand observed in irregular structures may result in unequal distribution of internal forces among columns and beams. Structural elements located at extreme corners experience substantially larger stresses than interior members, potentially leading to premature yielding and localized damage.

The findings emphasize the importance of considering torsional behavior during conceptual planning stages rather than relying solely on member strengthening during detailed design.

5.5 COMPARATIVE PERFORMANCE EVALUATION

To establish a comprehensive understanding of seismic behavior, all analytical models were compared based on five critical performance indicators:

- Fundamental Time Period
- Roof Displacement
- Maximum Storey Drift
- Base Shear
- Torsional Amplification

The performance ranking was developed by assigning equal weightage to each parameter.

Table 8. Comparative Performance Ranking

Model	Overall Seismic Performance Rank
Regular Building	1
L-Shaped Building	2
T-Shaped Building	3
U-Shaped Building	4

The regular building consistently demonstrated superior performance in all evaluated categories. Its symmetrical configuration enabled uniform force distribution and minimized torsional effects.

The L-shaped building exhibited moderate deterioration in performance due to the presence of a single re-entrant corner. Nevertheless, its behavior remained significantly better than that of the T-shaped and U-shaped configurations.

The T-shaped structure displayed increased displacement, drift, and torsional response due to the extension of structural wings away from the primary stiffness core.

The U-shaped building exhibited the least favorable seismic performance. The combination of multiple re-entrant corners and substantial geometric asymmetry produced amplified torsional behavior and larger deformation demands.

The comparative assessment clearly demonstrates that increasing plan irregularity leads to progressive deterioration in seismic performance.

5.6 ENGINEERING IMPLICATIONS FOR DESIGN PRACTICE

The findings obtained from the present investigation possess significant implications for practical structural design.

Modern architectural requirements frequently encourage the adoption of irregular building forms. While such configurations may satisfy functional and aesthetic objectives, they often introduce substantial seismic vulnerabilities that must be addressed through appropriate engineering measures.

The results indicate that plan irregularity should not be treated merely as an architectural consideration. Instead, it should be recognized as a critical structural parameter directly influencing seismic safety.

Several practical recommendations emerge from the study:

A. Early Structural Involvement
Structural engineers should participate during the conceptual planning stage to evaluate potential irregularities before finalization of architectural layouts.

B. Use of Shear Walls
Strategically located shear walls can significantly reduce displacement and torsional effects in irregular buildings.

C. Symmetrical Stiffness Distribution
Efforts should be made to maintain symmetry in stiffness distribution even when architectural geometry is irregular.

D. Seismic Separation Joints
Large irregular structures may be divided into smaller regular segments using seismic separation joints to minimize torsional interaction.

E. Performance-Based Design
For highly irregular buildings, nonlinear performance-based evaluation procedures should be considered instead of relying solely on code-based force design approaches.

Implementation of these measures can substantially improve structural reliability during severe seismic events.

5.7 DISCUSSION OF RESULTS IN RELATION TO PREVIOUS RESEARCH
The findings obtained in the present investigation exhibit strong agreement with previously published research on irregular buildings.

Several researchers have reported that plan irregularity leads to increased displacement and drift demands. Similar trends were observed in the current study, where the U-shaped building exhibited approximately 48 percent greater displacement than the regular building.

The observed increase in torsional amplification is also consistent with conclusions reported by Chopra, Goel, Humar, and Tso. These researchers identified torsional response as one of the primary mechanisms responsible for poor seismic performance in asymmetric structures.

The progressive increase in natural period observed from regular to irregular configurations further supports earlier investigations demonstrating that geometric discontinuities reduce effective lateral stiffness.

The close agreement between the present findings and existing literature validates the adopted analytical methodology and confirms the reliability of the obtained results.

5.8 LIMITATIONS OF THE PRESENT STUDY
Although the study provides valuable insight into the influence of plan irregularity on seismic behavior, certain limitations must be acknowledged.

Firstly, only linear elastic response spectrum analysis was performed. Actual structural response during severe earthquakes may involve nonlinear behavior, stiffness degradation, cracking, and energy dissipation mechanisms that are not captured in the present analysis.

Secondly, soil-structure interaction effects were not considered. Foundation flexibility can significantly influence dynamic characteristics, particularly for high-rise buildings.

Thirdly, the study was limited to reinforced concrete moment-resisting frame systems. Buildings employing shear walls, braced frames, or dual systems may exhibit different response characteristics.

Finally, only plan irregularity was investigated. Vertical irregularities such as soft storeys, mass discontinuities, and setback configurations were not included within the scope of the study.

Despite these limitations, the investigation provides meaningful understanding of the relative influence of plan irregularity on seismic performance and establishes a strong basis for future research.

VI. CONCLUSION

The present investigation evaluated the seismic performance of reinforced concrete multistorey buildings possessing different plan configurations using Response Spectrum Analysis in accordance with IS 1893 (Part 1): 2016. Four analytical models consisting of a Regular Rectangular Building, L-Shaped Building, T-Shaped Building, and U-Shaped Building were developed and analyzed using ETABS software. The study focused on understanding the influence of plan irregularity on critical seismic response parameters including natural period, storey

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DOI: https://doi.org/10.64388/IREV10I1-1720250

displacement, storey drift, base shear, torsional amplification, and overall structural performance.

Based on the analytical investigation and comparative evaluation of results, the following conclusions may be drawn:

6.1 Influence of Plan Geometry on Dynamic Characteristics
The study clearly demonstrates that plan geometry has a significant influence on the dynamic characteristics of reinforced concrete buildings. As the degree of plan irregularity increases, the effective lateral stiffness of the structure decreases, resulting in increased natural vibration periods.

The regular rectangular building exhibited the lowest fundamental period because of its symmetrical geometry and balanced stiffness distribution. In contrast, the U-shaped building demonstrated the highest natural period due to its pronounced geometric discontinuities and reduced structural rigidity.

The increase in vibration period observed in irregular buildings indicates greater flexibility and enhanced susceptibility to earthquake-induced deformation.

6.2 Effect on Lateral Displacement
Maximum roof displacement increased progressively with increasing plan irregularity. The regular building recorded the lowest lateral displacement, while the U-shaped configuration exhibited the highest displacement response.

The increase in displacement demand observed in irregular buildings can be attributed to:
• Reduced lateral stiffness
• Increased eccentricity
• Torsional coupling effects
• Non-uniform force distribution

6.3 Effect on Storey Drift
Storey drift analysis revealed that plan irregularity directly influences inter-storey deformation demands. The U-shaped and T-shaped buildings generated the highest drift values due to increased torsional effects and localized stiffness discontinuities.

Although all analytical models satisfied code-prescribed drift limitations, irregular buildings approached allowable limits more rapidly than the regular structure.

Since excessive drift often governs damage to non-structural elements, this observation has important implications for serviceability and post-earthquake functionality.

6.4 Influence on Base Shear
The analysis demonstrated a gradual increase in base shear demand as plan irregularity increased. The irregular configurations attracted larger seismic forces because of altered modal characteristics and dynamic amplification effects.

Among the considered models, the U-shaped building generated the highest base shear demand, indicating the necessity of designing stronger lateral force-resisting systems in highly irregular structures.

6.5 Torsional Response Behaviour
One of the most significant findings of the investigation relates to torsional response.

The regular building exhibited negligible torsional amplification due to coincidence of the center of mass and center of rigidity. However, irregular configurations developed substantial torsional response because of eccentricity introduced by geometric asymmetry.

The U-shaped building showed the highest torsional amplification factor, followed by the T-shaped and L-shaped configurations.

This finding confirms that torsional effects represent one of the primary causes of poor seismic performance in irregular structures.

6.6 Comparative Structural Performance
The overall seismic performance ranking developed during the investigation indicates the following order of structural efficiency:

Regular Building > L-Shaped Building > T-Shaped Building > U-Shaped Building

The regular building consistently exhibited superior performance across all evaluated parameters, whereas the U-shaped building demonstrated the least favorable response.

6.7 Practical Engineering Recommendations

Based on the analytical observations, the following recommendations are proposed for engineering practice:

- Symmetrical plan configurations should be preferred whenever possible.
- Re-entrant corners should be minimized during architectural planning.
- Shear walls should be strategically incorporated in irregular structures.
- Torsional effects must be explicitly considered during seismic analysis.

6.8 Overall Conclusion

The study conclusively demonstrates that plan irregularity has a substantial impact on the seismic behavior of reinforced concrete multistorey buildings. Increasing irregularity leads to greater displacement, higher drift demand, increased base shear, and amplified torsional response.

Among the investigated configurations, the regular rectangular building exhibited the most favorable seismic performance, whereas the U-shaped building displayed the greatest vulnerability under earthquake loading.

The results emphasize the necessity of integrating structural considerations into architectural planning to ensure safe and economical seismic design.

VII. FUTURE SCOPE

Although the present investigation provides a comprehensive assessment of plan irregularity effects, several opportunities remain for future research.
Future investigations may include:

7.1 Nonlinear Static Analysis

The current study utilized linear elastic response spectrum analysis. Future studies may employ nonlinear pushover analysis to evaluate structural behavior beyond the elastic range and determine actual collapse mechanisms.

7.2 Nonlinear Time History Analysis

Ground motion records from actual earthquakes may be used to investigate structural performance under realistic seismic excitations.

Time history analysis would provide deeper insight into:

- Inelastic behavior
- Energy dissipation mechanisms
- Progressive damage development
- Residual displacement characteristics

7.3 Soil-Structure Interaction

Future research may incorporate foundation flexibility and soil-structure interaction effects.

Different soil conditions including:

- Hard Soil
- Medium Soil
- Soft Soil

may be evaluated to determine their influence on irregular structures.

7.4 Performance-Based Seismic Design

The adoption of performance-based design methodologies can provide a more realistic assessment of structural performance under varying hazard levels.

Future studies may evaluate:

- Immediate Occupancy Performance
- Life Safety Performance
- Collapse Prevention Performance

7.5 Dual Structural Systems

Future investigations may compare:

- Moment Resisting Frames
- Shear Wall Systems
- Braced Frames
- Dual Systems

for various irregular building configurations.

7.6 Influence of Vertical Irregularities

Additional research may examine the combined influence of:

- Soft Storey Irregularity
- Mass Irregularity
- Setback Irregularity
- Floating Columns

on seismic response.

7.7 Artificial Intelligence Applications
Recent developments in Artificial Intelligence and Machine Learning provide new opportunities for structural engineering research.

Future studies may develop predictive models capable of estimating:
- Storey Drift
- Seismic Vulnerability
- Damage Probability
- Structural Health Condition

based on geometric and structural parameters.

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