

The Seismic Behaviour of Plan Irregularity in Mid-Rise Reinforced Concrete Structures Using Response Spectrum and Pushover Analysis

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1. Abstract

Earthquakes remain one of the most destructive natural hazards affecting the safety and serviceability of reinforced concrete (RC) buildings. In recent years, the demand for architecturally attractive and functionally efficient structures has resulted in the construction of buildings with irregular floor plans. Although such configurations satisfy aesthetic and functional requirements, they often exhibit poor seismic performance due to the uneven distribution of mass, stiffness, and lateral load-resisting elements. Plan irregularities such as L-shaped, U-shaped, C-shaped, and diaphragm discontinuity buildings generate significant torsional effects, resulting in increased storey drift, displacement, and stress concentration during earthquake excitation. Therefore, understanding the seismic response of these irregular structures has become an essential aspect of earthquake-resistant structural design.

The present study investigates the seismic behaviour of mid-rise reinforced concrete buildings having different plan irregularities by comparing their performance with that of a regular rectangular building. Structural modelling and analysis were carried out using ETABS software in accordance with the provisions of IS 1893:2016. Dynamic analysis was performed using the Response Spectrum Method, while the nonlinear behaviour and structural performance were evaluated through Pushover Analysis. Critical seismic parameters such as base shear, lateral displacement, storey drift, torsional response, stiffness, and capacity curves were analysed to determine the influence of plan irregularity on overall structural performance.

The study indicates that regular buildings provide a more uniform distribution of seismic forces, whereas irregular buildings experience larger torsional moments, uneven displacement patterns, and greater seismic demand. Among the analysed models, the diaphragm discontinuity configuration attracted the highest base shear, while the U-shaped configuration showed significant lateral displacement because of torsional effects. The findings highlight the importance of incorporating advanced seismic analysis methods during the design stage of irregular buildings. The research also demonstrates that pushover analysis provides valuable information regarding structural capacity and performance levels beyond the elastic range, thereby contributing to safer and more economical earthquake-resistant design practices.

Keywords: Plan Irregularity, Earthquake Engineering, Reinforced Concrete Structure, ETABS, Response Spectrum Analysis, Pushover Analysis, Base Shear, Storey Drift.

1. Introduction

Earthquakes are among the most severe natural disasters responsible for significant structural damage, economic loss, and human casualties throughout the world. The safety of buildings during seismic events depends not only on the strength of construction materials but also on the geometric configuration and structural arrangement of the building. Reinforced concrete buildings with regular floor plans generally perform better during earthquakes because the distribution of mass and stiffness remains symmetrical, allowing seismic forces to be transferred uniformly throughout the structure. However, rapid urbanization and modern architectural trends have encouraged the construction of buildings with irregular layouts, including L-shaped, U-shaped, C-shaped, and diaphragm discontinuity configurations. These irregular forms provide better architectural flexibility but often create complex seismic behaviour that increases the vulnerability of structures during earthquakes.

Plan irregularity causes an uneven distribution of stiffness and mass, resulting in eccentricity between the centre of mass and the centre of rigidity. This eccentricity produces torsional effects during seismic excitation, causing larger lateral displacements, excessive storey drift, stress concentration, and potential structural failure. Modern seismic design codes such as

IS 1893:2016 recognize these issues and recommend advanced dynamic analysis methods for irregular buildings instead of relying solely on equivalent static analysis. Consequently, structural engineers increasingly employ Response Spectrum Analysis and nonlinear Pushover Analysis to evaluate the seismic performance of irregular reinforced concrete buildings more accurately.

The present research focuses on analysing the seismic behaviour of various plan-irregular mid-rise RC structures using ETABS software. Different building configurations are modelled and subjected to earthquake loading according to Indian seismic code provisions. The seismic responses of the irregular models are compared with those of a regular rectangular building based on important engineering parameters such as base shear, displacement, torsional response, storey drift, and structural capacity. The study aims to improve the understanding of how different plan irregularities influence seismic performance and to provide recommendations for safer structural design. The outcomes of this research contribute to enhancing earthquake-resistant construction practices, particularly in moderate and high seismic zones where irregular building configurations are increasingly common.

2. Materials and Methods

The present research investigates the seismic behaviour of plan-irregular reinforced concrete (RC) buildings by performing a comparative analytical study on different structural configurations. A regular rectangular building was selected as the reference model, while L-shaped, U-shaped, C-shaped, and diaphragm discontinuity models were developed to evaluate the influence of plan irregularity on structural performance under earthquake loading. The building models were created using ETABS software, which is widely recognized for structural analysis and design of multi-storey buildings. All models were designed in accordance with the recommendations of IS 1893 (Part 1):2016 and relevant reinforced concrete design provisions.

The study considered a G+7 reinforced concrete building located in Seismic Zone III, representing conditions similar to those applicable in Pune. The structural system consisted of M25 grade concrete and Fe415 reinforcing steel. Standard beam, column, and slab dimensions were adopted to maintain uniformity among all structural models. Dead loads, live loads, and seismic loads were assigned according to Indian Standard specifications. The Response Reduction Factor, Importance Factor, soil type, and damping ratio were selected as per IS 1893:2016 to ensure realistic seismic analysis.

Dynamic analysis was performed using the Response Spectrum Method because it provides a more accurate estimation of structural response than the equivalent static method, particularly for irregular buildings.

The method evaluates the maximum probable response of the structure by considering several vibration modes and combining their effects. Important parameters such as base shear, lateral displacement, storey drift, and torsional behaviour were extracted from the analysis results for comparison among different building configurations.

To evaluate structural performance beyond the elastic range, nonlinear static pushover analysis was also performed. Plastic hinge properties were assigned to beams and columns to simulate inelastic behaviour under increasing lateral loading. Capacity curves relating base shear and roof displacement were generated to determine the lateral load-carrying capacity and deformation characteristics of each structural model. The combined use of Response Spectrum Analysis and Pushover Analysis enabled a comprehensive evaluation of both linear and nonlinear seismic behaviour, providing a reliable basis for comparing the seismic performance of regular and irregular reinforced concrete buildings.

3. Results

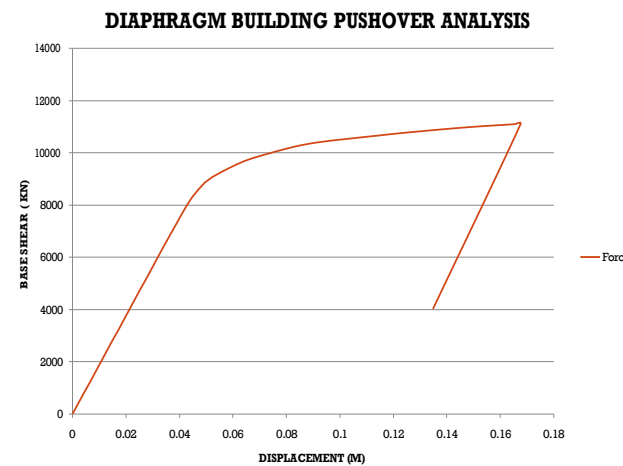
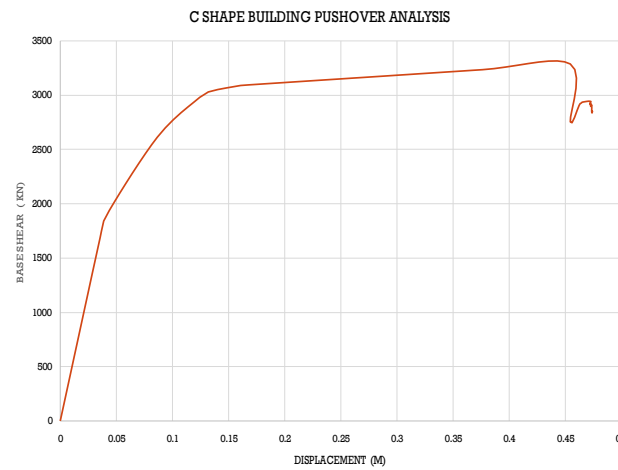
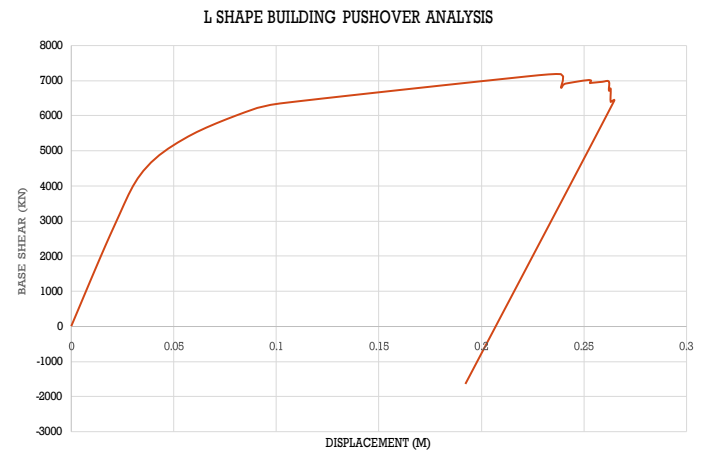
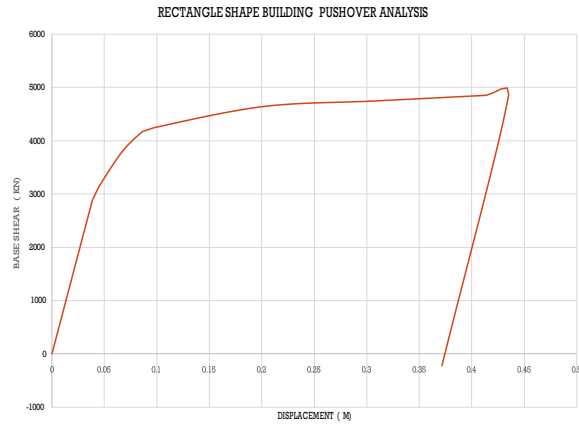
The analytical results clearly demonstrate that the seismic response of reinforced concrete buildings is significantly influenced by plan irregularity. The regular rectangular building exhibited the most balanced structural behaviour because of its uniform distribution of mass and stiffness. Consequently, seismic forces were transferred efficiently throughout the structure, resulting in comparatively lower torsional effects and a more uniform displacement pattern.

The diaphragm discontinuity model attracted the highest base shear in both the X and Y directions, indicating that interruptions in floor diaphragm continuity considerably increase the seismic demand on the structural system. The concentration of stiffness around discontinuous regions produced higher lateral force requirements, making this configuration the most critical among the analysed models. The U-shaped building experienced the greatest lateral displacement because of pronounced torsional behaviour arising from its asymmetric geometry. This behaviour suggests that buildings with re-entrant corners require additional seismic design considerations to limit excessive deformation.

The L-shaped building recorded comparatively lower base shear and displacement values. However, despite these lower numerical values, irregular geometry still generated torsional effects that could become significant under severe earthquake excitation. The pushover analysis further revealed differences in nonlinear performance among the structural models.

The diaphragm discontinuity building exhibited the highest lateral strength, while the rectangular model demonstrated superior ductility and stable post-elastic behaviour. The C-shaped structure showed comparatively lower lateral load-carrying capacity but maintained reasonable deformation capability before failure.

Overall, the results indicate that regular buildings provide better seismic performance due to their symmetrical configuration. Plan-irregular buildings require more rigorous seismic evaluation because torsional response, stiffness irregularity, and uneven displacement distribution can significantly increase structural vulnerability during strong ground motion. These findings confirm the necessity of advanced dynamic and nonlinear analysis methods during the design stage of irregular reinforced concrete buildings.



MODEL SHAPE	APPROX. MAXIMUM BASE SHEAR (KN)	APPROX. MAXIMUM DISPLACEMENT (M)	KEY OBSERVATIONS
RECTANGULAR	5000	0.45	Highest Ductility & Stable Nonlinear Response.
L-SHAPE	7000	0.26	Higher Strength with Moderate Ductility, affected by Torsion.
C-SHAPE	3300	0.45	Lowest Lateral Strength but Good Deformation Capacity.
DIAPHRAGM	11000	0.17	Highest Stiffness & Lateral Load Resistance.

4. Discussion

The present investigation confirms the observations reported in previous seismic research, which indicate that plan irregularity has a considerable influence on the earthquake resistance of reinforced concrete buildings. The comparison of regular and irregular structural configurations demonstrated that asymmetrical layouts alter the natural dynamic characteristics of the structure and produce complex load transfer mechanisms during earthquake excitation. The uneven distribution of stiffness and mass results in eccentricity between the centre of mass and the centre of rigidity, generating torsional moments that increase structural demand beyond that observed in regular buildings.

Response Spectrum Analysis proved to be an effective method for evaluating the dynamic behaviour of irregular structures because it considers the contribution of multiple vibration modes. Compared with equivalent static analysis, this method provides a more realistic estimation of seismic response, particularly for medium-rise buildings having complex geometrical configurations. Similarly, pushover analysis enabled the assessment of structural performance beyond the elastic range by identifying plastic hinge formation and estimating the ultimate load-carrying capacity of each structural model. These analyses together provide a comprehensive understanding of the behaviour of irregular buildings under seismic loading.

The findings also emphasize the importance of complying with the provisions of IS 1893:2016 while designing irregular

structures. Appropriate placement of shear walls, improvement of diaphragm continuity, reduction of torsional eccentricity, and symmetrical distribution of stiffness can significantly enhance seismic performance. Engineers should adopt performance-based seismic design principles, particularly for buildings located in moderate and high seismic zones. Future developments in finite element modelling and nonlinear dynamic analysis will further improve the accuracy of seismic performance assessment and contribute to the construction of safer, more resilient reinforced concrete structures.

5. Conclusion

The present study evaluated the seismic behaviour of mid-rise reinforced concrete (RC) buildings with different plan irregularities using Response Spectrum Analysis and Pushover Analysis in ETABS. A comparative assessment was carried out between a regular rectangular building and various irregular configurations, including L-shaped, U-shaped, C-shaped, and diaphragm discontinuity models, to understand the influence of plan irregularity on structural performance during earthquake loading. The analysis demonstrated that the geometry of a building plays a significant role in determining its seismic response, particularly with respect to base shear, storey displacement, torsional effects, and overall structural stability.

The results revealed that the regular rectangular building exhibited the most balanced and predictable seismic behaviour because of its symmetrical distribution of

mass and stiffness. In contrast, plan-irregular buildings experienced greater torsional effects, uneven force distribution, and increased lateral displacement. Among the analysed models, the diaphragm discontinuity configuration attracted the highest base shear, indicating greater seismic force demand, while the U-shaped building showed significant lateral displacement due to torsional irregularity. Although the L-shaped structure recorded comparatively lower displacement values, its asymmetric geometry still made it susceptible to torsional response during strong earthquake excitation. These observations confirm that plan irregularity significantly affects the seismic performance of reinforced concrete buildings and therefore requires careful consideration during structural design.

The pushover analysis further demonstrated the importance of evaluating the nonlinear behaviour of structures beyond the elastic range. Capacity curves showed that different building configurations possess different levels of strength, stiffness, and ductility. The regular building displayed a stable nonlinear response with good deformation capacity, whereas irregular buildings exhibited variations in load-carrying capacity depending on their structural configuration. These findings highlight that relying only on conventional linear analysis may not provide a complete understanding of structural performance under severe seismic loading.

Overall, the study concludes that advanced analytical methods such as Response Spectrum Analysis and Pushover Analysis are essential for accurately evaluating the seismic behaviour of plan-irregular RC

structures. Strict compliance with IS 1893:2016 codal provisions, combined with appropriate structural planning and performance-based design approaches, can significantly improve earthquake resistance and ensure the safety, serviceability, and durability of buildings constructed in seismic regions. The outcomes of this research provide valuable guidance for structural engineers and researchers in designing safer and more resilient reinforced concrete buildings.

6. Future Scope

The present study provides a comprehensive understanding of the seismic behaviour of plan-irregular reinforced concrete (RC) buildings using Response Spectrum Analysis and Pushover Analysis. However, several opportunities remain for further research to improve the seismic safety and performance of irregular structures. Future studies may investigate taller buildings (G+15, G+20, and above) to evaluate how increasing height influences seismic response, torsional effects, and structural stability. Since high-rise buildings possess more complex dynamic characteristics, advanced analytical methods can provide deeper insights into their behaviour under strong earthquake ground motions.

Further research can also incorporate Nonlinear Time History Analysis, which provides a more realistic representation of structural response by considering actual earthquake ground motion records. Unlike

response spectrum analysis, time history analysis captures the complete variation of displacement, acceleration, and internal forces throughout the duration of an earthquake, thereby improving the accuracy of seismic performance assessment. The influence of different soil conditions, foundation flexibility, and soil–structure interaction may also be investigated to better understand their effect on the seismic behaviour of irregular reinforced concrete buildings.

Another important area for future research is the use of advanced seismic protection systems such as base isolation, energy dissipation devices, viscous dampers, and tuned mass dampers to reduce lateral

displacement and improve structural performance. The effectiveness of different shear wall arrangements, bracing systems, and composite structural components can also be examined for various plan irregularities. In addition, the application of performance-based seismic design, Building Information Modelling (BIM), Artificial Intelligence (AI), and machine learning techniques can assist engineers in optimizing structural design and predicting seismic performance more efficiently. These developments will contribute to the construction of safer, more economical, and sustainable earthquake-resistant buildings capable of withstanding future seismic hazards.

References

- [1] S. Sivakumar, R. Shobana, E. Aarthy, S. Thenmozhi, V. Gowri, and B. S. C. Kumar, "Seismic Analysis of Plan Irregular Building," *Materials Today: Proceedings*, vol. 72, pp. 1–8, 2023.
- [2] P. K. Das, S. C. Dutta, and T. K. Datta, "Seismic Behavior of Plan and Vertically Irregular Structures: State of the Art and Future Challenges," *Natural Hazards Review*, vol. 21, no. 3, 2020.
- [3] N. M. Naganur and Vijaykumar, "Effect of Seismicity on Irregular Shape Structure," *International Journal of Civil Engineering and Technology (IJCET)*, vol. 9, no. 13, pp. 2248–2264, 2018.
- [4] S. A. Halkude, C. G. Konapure, and C. A. Madgundi, "Seismic Analysis of RC Building (G+9) by Response Spectrum Method," *International Journal of Engineering Research & Technology (IJERT)*, vol. 3, no. 6, pp. 1–6, 2014.
- [5] J. Browning, B. Warden, A. Matamoros, and A. Lepage, "Global and Local Seismic Drift Estimates for Reinforced Concrete Structures," *Engineering Structures*, vol. 30, no. 5, pp. 1248–1262, 2008.
- [6] Bureau of Indian Standards, IS 1893 (Part 1): 2016, *Criteria for Earthquake Resistant Design of Structures – General Provisions and Buildings*, New Delhi, India, 2016.
- [7] Bureau of Indian Standards, IS 456:2000, *Plain and Reinforced Concrete – Code of Practice*, New Delhi, India, 2000.
- [8] Bureau of Indian Standards, IS 875 (Part 1):1987, *Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures – Dead Loads*, New Delhi, India.
- [9] Bureau of Indian Standards, IS 875 (Part 2):1987, *Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures – Imposed Loads*, New Delhi, India.
- [10] Computers and Structures, Inc., ETABS 21 – *Integrated Building Design Software User Guide*, Berkeley, California, USA.
- [11] International Code Council, *Uniform Building Code (UBC 1997/1998)*, Volume 2: *Structural Engineering Design Provisions*, California, USA.
- [12] European Committee for Standardization, Eurocode 8: *Design of Structures for Earthquake Resistance (EN 1998-1)*, Brussels, Belgium, 2004.