International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 04 | Apr 2026 www.irjet.net p-ISSN: 2395-0072

Review Paper on seismic Analysis of High-Rise Building with Plan and Vertical Irregularity

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Abstract – *This investigation assesses the seismic performance of high-rise RC and steel buildings (G+10 to G+49) featuring complex plan and vertical irregularities. Using advanced finite element software and nonlinear time-history analysis, the study demonstrates that features like torsional asymmetry, re-entrant corners, and "soft stories" significantly amplify inter-story drift and shear stresses compared to regular models. The results indicate that mass irregularities and geometric setbacks lead to abrupt changes in lateral stiffness, causing earlier entry into the non- linear range. Consequently, the research highlights that traditional prescriptive codes often un- Der estimate seismic demands, necessitating the adoption of performance-based seismic design (PBSD) to ensure the resilience of modern urban infrastructure.*

This study demonstrates that architectural irregularities significantly increase seismic vulnerability by creating localized structural weaknesses. Plan irregularities, such as torsional coupling and re-entrant corners, cause excessive inter-story drift due to the eccentricity between the center of mass and rigidity. Vertical discontinuities, including "soft stories" and geometric setbacks, trig- ger abrupt stiffness changes that lead to premature nonlinear failure. Additionally, mass irregularities from heavy equipment or pools on upper floors substantially increase base shear demands. Ultimately, the research finds that traditional building codes often underestimate these effects, advocating for performance-based seismic design (PBSD) and nonlinear time-history analysis to ensure high-rise resilience.

Key Words: Seismic Analysis, Stiffness Irregularity, Torsional Irregularity, Story Drift, Base Shear.

1. INTRODUCTION

1.1 General

The structural integrity and seismic resilience of high-rise buildings remain paramount in modern urban planning, as theism are increasingly subjected to unpredictable and devastating seismic excitations. Modern tall buildings utilize high-strength materials and efficient structural systems, resulting in more slender, flexible configurations with lower damping ratios that are highly sensitive to lateral forces induced by wind and earthquakes. While conventional design philosophies prioritize adequate lateral strength, stiffness, and ductility, the rapid growth of urbanization has necessitated the construction of buildings with complex, unsymmetrical configurations for both functional and aesthetic requirements. These architectural demands often introduce structural discontinuities that compromise the predictable seismic response seen in regular structures. Consequently, advancing seismic analysis through methodologies such as nonlinear time-history analysis and performance-based seismic design is essential to quantify structural vulnerabilities and ensure occupant safety in severe seismic zones.

1.2 Concept of irregularity

Structural irregularity in high-rise buildings arises from abrupt discontinuities in mass, stiffness, or geometry that disrupt the uniform flow of lateral forces. Plan irregularity-es, such as torsional asymmetry and re-entrant corners, create significant eccentricity be- tween the centers of mass and rigidity, amplifying shear stresses and story drift. Vertically, "soft stories," geometric setbacks, or concentrated mass loads (exceeding 150- 200% of adjacent levels per IS 1893) alter dynamic properties and cause localized weaknesses. These factors collectively increase seismic vulnerability, often leading to premature nonlinear behavior and a higher risk of collapse compared to symmetric structures.

2. LITERATURE REVIEW

Manoj Kumar Sharma & Hemant Kumar Sain (2024) provides an extensive investigation into the seismic analysis of high-rise and interconnected structural systems, while concurrently documenting the historical evolution of vertical construction. The authors highlight that the proximity of interconnected buildings creates complex dynamic interactions that can significantly alter seismic impact compared to isolated structures. Defining skyscrapers as edifices exceeding 40 floors or 150 meters, the study notes how high-strength materials and modern elevator technology have enabled these mega-structures. By synthesizing historical milestones from ancient ziggurats to steel- framed towers, the paper emphasizes that contemporary designs must incorporate structural barriers to mitigate wind loads and ensure occupant comfort. Ultimately, the re- view concludes that as urbanization intensifies, advancing seismic analysis and under- standing structural interdependencies are vital for maintaining the resilience of modern urban environments. [1]

Apoorva & Sushma C K (2021) presents a comparative seismic performance evaluation of 30-story vertically irregular RC high-rise buildings located in seismic zone IV. Using ETABS software to model regular, setback, mass-irregular, and stepped config- unrations, this study assessed seismic performance based on IS 1893:2016 standards. Through response spectrum and static pushover analyses, the research evaluated story drift, ductility ratios, and performance points. The results revealed that while all models stayed within safety limits, the stepped configuration exhibited the highest story drift in upper levels, whereas the setback model achieved the greatest global ductility. Ulti- matily, the study concludes that geometric irregularities impact seismic drift more significantly than mass irregularities, requiring more rigorous design focus for structures in high-seismic zones. [2]

Anjeet Singh Chauhan & Rajiv Banerjee (2021) performed research over a G+10 RCC step back building was modeled and analyzed using ETABS software to investigate seismic performance on sloping ground. This study analyzed four configure- rations—bare step back, mass-irregular, diaphragm-irregular, and combined-irregular frames—on various slope inclinations in seismic zone V. Using the Response Spectrum Method, the research found that steeper slopes increase structural stiffness, which in turn attracts higher lateral forces, base shear, and story displacement. Results identified the mass-irregular step back frame (Model-2) on a 45° slope as the most vulnerable due to excessive seismic weight. In contrast, the diaphragm-irregular frame (Model-3) on a 20° slope proved the most stable and least susceptible to seismic hazards. [3]

Behzad Mohammadzadeh & Junsuk Kang (2019) made study of 12-story high-rise steel moment-resisting frame building, with a total height of 41.6 m, was modeled and analyzed using a combination of SAP2000 and ABAQUS software This study compared three structural cases—regular, torsion ally irregular (plan), and stiff- ness-irregular (vertical soft story)—using SAP2000 for design and ABAQUS for non- linear time-history analysis based on the Vrancea Earthquake data. By modeling structural members as wire elements for computational efficiency, the research evaluated deformed shapes, reactions, and story drifts. The results confirm that regular buildings exhibit superior seismic performance with minimal deformation. Notably, the study concludes that plan irregularity (torsion) triggers the most severe seismic response, producing higher story drifts than both regular and vertically irregular configurations. [4]

Ravindra N. Shelke & U. S. Ansari (2017) investigated a 15-story (G+14) vertically irregular RC building frame was modeled and analyzed using ETABS software. This study evaluated vertical irregularities—specifically mass (swimming pools), stiffness (ground-level soft stories), and geometric setbacks—using equivalent static and Re- sponse Spectrum Analysis (RSA) for seismic zone III. Results show that mass-irregular buildings experience significantly higher base shear, while stiffness-irregular structures exhibit reduced base shear but much larger inter-story drifts. Ultimately, the study con- cludes that dynamic analysis is essential for irregular high-rises, as the equivalent static method is overly conservative and fails to capture the non-linear distribution of seismic forces. [5]

Kusuma B (2017) conducted research over a 50-story (G+49) high-rise RC framed structure with an unsymmetrical plan was modeled and analyzed using ETABS software. The study evaluated the impact of five specific irregularities: re-entrant corners, mass irregularity, vertical geometric irregularity, diaphragm discontinuity, and stiffness irregularity. Seismic analysis was conducted using the response spectrum method for seismic zone IV and soil type III conditions. Key structural response parameters, including mode period, lateral displacement and story drift, base shear, and story stiffness, were obtained. The results indicate that story stiffness is significantly reduced in all irregular models compared to the regular control structure. Notably, the re-entrant corner con- figuration demonstrated the worst seismic performance, exhibiting the highest lateral displacement and story drift. Furthermore, the study observed that mass irregularity resulted in the highest base shear due to increased seismic mass, while stiffness-irregular models exhibited the longest mode periods. [6]

Ali Ruzi Özuygur (2015) a 50-story (198 m) reinforced concrete residential building with an extremely irregular floor plan was designed using performance-based seismic design (PBSD) principles. Located in Istanbul, Turkey, this structure consists of two high-rise blocks linked by slabs of varying stiffness across different floor levels. Per- formance was evaluated using linear response spectrum analysis for the Design Basis Earthquake (DBE) and nonlinear time-history analysis (NLTHA) via PERFORM-3D for the Maximum Considered Earthquake (MCE). The findings revealed that traditional elastic analysis significantly underestimated shear demands in walls compared to NLTHA, necessitating additional reinforcement. Furthermore, axial forces in shear walls at the irregular plan's boundaries exceeded safety limits during MCE events, requiring capacity redesigns. Ultimately, the study concludes that Performance-Based Seismic Design (PBSD) provides a more accurate assessment of displacements and higher-mode effects for complex, irregular high-rise buildings. [7]

Dileshwar Rana & Prof. Juned Raheem (2015) a comparative seismic analysis of regular and vertical geometric irregular RCC building frames was performed using STAAD.Pro V8i. This study analyzed 40 building models, ranging from 4 to 16 stories, to evaluate the seismic impact of setbacks in zone IV. Results show that regular configurations consistently outperform irregular setback structures, which suffer from significantly higher shear forces and bending moments due to reduced structural stiffness. The findings indicate that four-bay frames are suitable for shorter buildings, while eight-bay configurations are more effective for taller structures (12–16 stories) as they minimize critical seismic parameters. Ultimately, among the irregular models tested, the Type V1 setback configuration demonstrated the best performance. [8]

Arvindreddy & R.J.Fernandes (2015) researched over 15-story (G+14) regular and irregular reinforced concrete frame structures were modeled and analyzed using ETABS 2013 software. Focusing on seismic zone V, this study evaluated five irregularities—mass, stiffness, diaphragm, re-entrant corner, and torsion—using static, response spectrum, and nonlinear pushover analyses, alongside a time-history simulation of the Bhuj earthquake. The results indicate that static analysis typically underestimates story displacement compared to the response spectrum method due to its inability to capture nonlinear force distributions. While diaphragm-irregular buildings showed lower drift than regular models, stiffness-irregular structures entered the non- linear range earlier and recorded the lowest base force during dynamic testing. Ultimately, the authors concluded that stiffness irregularities are particularly high-risk and noted that the performance of stiffness and diaphragm configurations can shift significantly as building height increases. [9]

Anupam Rajmani & Prof Priyabrata Guha (2015) In this research paper, the seismic and wind load performance of four different building plan geometries—circular, rectangular, square, and triangular—was investigated for high-rise structures This study analyzed buildings of 15, 30, and 45 stories with a constant base area to evaluate the impact of building shape on structural stability. Results indicated that performance varies significantly with height: for 15-story structures, circular shapes are most earth- quake-resistant, while triangular shapes excel under wind loads. At 30 stories, rectangular configurations are most stable for both load types, but at 45 stories, circular and rectangular shapes perform best for seismic and wind excitations, respectively. Ultimately, the study concludes that triangular and rectangular shapes experience the highest displacement at extreme heights, highlighting aerodynamic shaping as a critical, cost-effective strategy for minimizing lateral movement in tall buildings. [10]

S Monish & S Karuna (2015) 20-story RC ordinary moment-resisting frame building was modeled and analyzed using ETABS 2013 to evaluate the impact of plan irregularities. This study examined seven building configurations to assess the impact of diaphragm discontinuities (H, C, and +-shapes) and re-entrant corners (L-shapes with 40%, 60%, and 80% projections) in seismic zone V. Using both static and response spectrum methods, the research found that story displacement increases with height and is consistently higher in static models due to linear assumptions. The H-shaped model proved the most vulnerable diaphragm configuration, while seismic susceptibility in L- shaped models intensified as the re-entrant projection size increased, peaking at 80%. Ultimately, the study concludes that analytical fundamental periods provide a more accurate assessment than empirical formulas, noting that IS 1893:2002 standards do not fully capture the high-seismic risks associated with these complex irregularities. [11]

Khaled M. Heiza & Magdy A. Tayel (2012) In this research paper, a 15-story (G+14) reinforced concrete building was modeled and analyzed using ETABS 2013 software. Focusing on seismic zone V, this study compared a regular structure against five irregular models: mass, stiffness, diaphragm, re-entrant corner, and torsion. Performance was assessed using linear static, response spectrum, and nonlinear pushover analyses, alongside a time-history simulation of the Bhuj earthquake. The findings show that static analysis typically underestimates story displacement compared to the response spectrum method. Among the models, the stiffness-irregular structure entered the non- linear range earliest and recorded the lowest base force during dynamic testing. Ultimately, the research concludes that stiffness irregularities pose a high risk ("non-con- servative") and that the performance of stiffness versus diaphragm irregularities can shift significantly as building height increases. [12]

3. CONCLUSIONS

Reviewing numerous studies on high-rise structures confirms that seismic resilience is heavily compromised by structural and architectural asymmetries, which create localized weaknesses in lateral load-resisting systems. Regular configurations consistently outperform irregular models, showing lower deformation and more efficient energy dissipation. Plan irregularities—specifically torsional asymmetry and re-entrant corners pose the greatest threat by creating eccentricity between the centers of gravity and rigidity, leading to amplified shear stresses and excessive story drifts. Additionally, vertical setbacks and stiffness irregularities cause abrupt rigidity changes; while stiffness-irregular structures may show reduced base shear, they suffer from sharply increased inter-story drift and premature entry into the nonlinear behavior range.

Conventional linear static procedures often fail to accurately predict the dynamic response of irregular high-rises because they neglect complex mass-stiffness distributions, necessitating advanced methodologies like Performance-Based Seismic Design (PBSD) and Nonlinear Time-History Analysis (NLTHA) to evaluate higher-mode effects and plastic hinge development. While mass irregularities, such as upper-floor swimming pools, primarily increase inertial forces and base shear, geometric and plan asymmetries—specifically torsional coupling—exert a more profound impact on story drift and shear stress. From a structural dynamics' perspective, these discontinuities alter modal characteristics and concentrate stress in critical zones; while neglecting soil-structure interaction can lead to underestimating spectral acceleration demands on slender structures. To mitigate these risks, incorporating optimized aerodynamic shapes like circular or rectangular configurations and utilizing high-ductility link slabs are essential strategies to ensure structural resilience and energy dissipation during major seismic events.

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