International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Analysis Seismic Behavior of Structures with Planar Imperfections: A Comprehensive Numerical Analysis

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ABSTRACT

This paper presents a comprehensive approach to the seismic analysis and design of a tall hospital building, accounting for horizontal irregularities and employing equivalent static analysis (ESA) methodology. The study initiates with the collection of relevant site data and building specifications, including the identification and characterization of horizontal irregularities such as setbacks, mass distribution variations, and irregular floor plans. Equivalent static lateral loads are calculated based on applicable building codes and standards, taking into account the effects of horizontal irregularities on seismic response. Structural modeling and analysis are then conducted using sophisticated software to evaluate the building's behavior under seismic forces, considering the influence of irregularities on structural performance. Design criteria, encompassing drift limits, strength requirements, and detailing considerations for mitigating irregularity effects, are rigorously adhered to ensure compliance with safety regulations and performance objectives. The iterative process of evaluation and adjustment ensures optimal seismic performance and adherence to design criteria despite the presence of horizontal irregularities. Documentation of the analysis and design process, coupled with meticulous construction oversight, guarantees the implementation of a robust seismic design strategy tailored to the unique characteristics of the tall hospital building. Post-construction evaluations are carried out to validate predicted seismic performance, accounting for the influence of horizontal irregularities. Through collaborative efforts and adherence to best practices, the seismic design of the tall hospital building prioritizes safety and resilience, even in the face of horizontal irregularities, aiming to safeguard occupants and critical healthcare infrastructure during seismic events.

1.Introduction:

In recent years, the requirement to understand and anticipate the dynamic behaviour of structures under seismic loading has grown in importance, driven by the compelling need to design earthquake-resistant infrastructure. This is especially important when considering buildings with planar abnormalities, since these structures provide distinct issues that need nuanced solutions.

Planar irregularities, defined as differences in shape and geometry, present complexity that have a significant influence on the distribution of forces inside a structure. These abnormalities can cause non-uniform responses to seismic pressures, jeopardising the structural integrity and safety of the structure. Despite the predominance of irregular-shaped structures in modern architectural design, there remains a crucial gap in our understanding of their seismic behaviour, highlighting the significance of careful inquiry in this area.

The major goal of this research study is to close this gap by conducting a thorough numerical analysis of the seismic reactions of structures with planar imperfections. To this goal, four typical irregular forms - C, L, I, and T - were chosen as exemplary examples. These forms, which are often used in current architectural designs, include a wide range of geometrical imperfections, making them excellent candidates for study.

To further understand the dynamic properties of these irregular structures, the study applies complex modal and time history studies. The study's goal is to give a comprehensive knowledge of the seismic behaviour of structures with planar defects by investigating modal characteristics, base shear, roof displacement, acceleration, and drift. These calculations provide important insights into the intricate interplay between structural geometry and seismic reactions, offering light on the mechanisms that determine the behaviour of irregularly shaped structures under seismic loading.

The determination of the most relevant irregularity parameter influencing these structures' seismic response is a primary goal of this research. The study aims to determine the major mechanism driving the seismic behaviour of irregular structures by carefully defining and analysing several irregularity characteristics associated with planar geometry. This understanding is critical for designing effective design standards and mitigation techniques that are suited to the specific problems provided by planar abnormalities, hence increasing the resilience of infrastructure in seismically prone areas.

Furthermore, the study investigates the impact of various seismic events on irregular structures by submitting them to ground excitations with variable dominant frequencies. This thorough technique allows for an in-depth examination of the structures' reactions under various seismic situations, offering significant insights into their performance across a wide variety of scenarios.

In conclusion, the outcomes of this research project are expected to increase our understanding of seismic behaviour in structures with planar imperfections, providing practical insights for engineers, architects, and stakeholders engaged in the design and construction of resilient infrastructure. This work seeks to catalyse informed decision-making and promote the creation of safer and more resilient built environments in seismically prone areas by clarifying the complex interplay between structural geometry and seismic reactions.

2. Literature Review

Md. Naimul Haque et. al.2022: Understanding and anticipating building behaviour is critical for successful seismic design, especially for structures with planar imperfections. This work undertakes a rigorous numerical analysis to improve understanding of seismic reactions in such buildings. Four typical irregular forms (C, L, I, and T) are investigated. Two ground excitations with different dominant frequencies are used to mimic seismic occurrences. Modal and time history studies are used to forecast dynamic properties such as modal characteristics, base shear, roof displacement, roof acceleration, and drift. Various irregularity characteristics connected to planar geometry are specified in order to determine the most significant parameter on seismic reactions. The results show that the overall aspect ratio (L/B ratio) of buildings is strongly connected with seismic reactions. However, seismic responses differ greatly amongst irregular structures based on earthquake parameters and planar irregularity. Furthermore, I and T-shaped structures had the strongest seismic reactions among those evaluated.

Pranali U. Meshram and Deepa Telang (2020): Wind engineering has gained in importance in India in recent years since there has been a greater desire for higher and slimmer constructions. With a growing population and limited space, horizontal growth is becoming less practical, particularly in cities. Wind engineering, which is sometimes confused with wind energy, is concerned with understanding how wind affects structures and their surroundings. Wind loads on claddings are important for selecting cladding systems in buildings, whereas wind loads on structural elements influence the design of beams, columns, lateral bracing, and foundations. Wind usually becomes a deciding issue for projects taller than 150 metres. Another important stress on tall structures is the lateral load caused by seismic forces. As buildings grow in height, they become more flexible and move away from high-frequency earthquake waves. This article gives a wind and seismic analysis of tall structures in various parts of the Indian subcontinent, with a fifteen-story RCC structure as a case study. Wind loads are calculated using the Indian code IS 875 (Part 3)-1987. The study shows that wind loads grow with structural height and are more relevant for tall structures than seismic loads. Furthermore, buildings should be constructed to sustain loads in both directions individually in order to adequately account for significant wind forces.

Vishal N, R. Kannan M 2020: In their study, Vishal N, R. Kannan M, and colleagues used the response spectrum approach to investigate the structural behaviour of a 20-story structure with vertical roughness. Their investigation, which included and excluded building sequence analysis (CSA) and used several structural systems in CSI ETABS V16 as per BIS 1893: 2016 (Part 1), sought to analyse structural safety and economic efficiency. The study found that applying stresses sequentially for each floor had a substantial impact on both elements. The findings revealed a decrease in the top floor's maximum displacement, which was particularly noticeable in binary and linked systems. Increased stiffness was related with bigger fundamental frequency changes, and the binary system performed better in response spectrum analysis. Incorporating shear walls and fittings efficiently kept floor movement below acceptable limits. Modal analysis demonstrated that the binary system had a shorter period of structural reaction than the snapshot system, indicating superior seismic behaviour. A comparison of conventional analysis with CSA revealed variations in axial forces between outer and inner columns, with CSA typically resulting in larger axial forces in inner columns. Furthermore, an investigation of the bending moment distribution throughout the structure's height revealed variances, with a significant drop detected during construction sequence analysis, probably due to greater analysis cycles in lower levels. Overall, the study emphasises the importance of sequential loading and the effects of various structural systems on the seismic behaviour and performance of tall structures with vertical roughness.

Thejaswini R. M., L. Govindaraju, and V. Devaraj 2020: In their study, investigated the dynamic behaviour of buildings, including normal five-story structures, symmetrical and asymmetrical buildings with longitudinal and transverse compartments. The major goal was to compare irregularity indicators from several building codes, including IS: 1893-2016, Euro Code 8-2004, and ASCE 7.05-2005. Seismic impacts were investigated using time history analysis, which assessed characteristics such as the basic vibration period, displacement, and structural reaction. A comparison was made between symmetric deviation structures (SSB) and asymmetric deceleration structures (ASB), which have different roughness indices as per IS: 1893-2016 and comparable indices as per Euro Code-8 (2004) and ASCE 7.05. Comparisons of lateral and floor displacements during seismic excitations indicated commonalities between symmetrical recession and asymmetric recovery structures, despite variations in irregularity indices (IS: 1893–2016).

Bilal Ahmad Lone; Jagdish Chand (2019): This work undertakes a literature analysis on the seismic and wind performance of regular and irregular buildings, taking into account changes in height and terrain type. Previous constructions are modelled and analysed using ETABS software, with a focus on form and Zone-V categorization. Seismic analysis corresponds to IS 1893-2016, whereas wind analysis adheres to IS 875 Part III. The parameters analysed include storey drift, displacement, base shear, overturning moment, acceleration, and time period. The results show that differences between regular and irregular models cause changes in displacement and drift owing to lateral pressures operating on both types of structures.

Archana. J. Satheesh, B. R. Jayalekshmi and Katta Venkataramana: Real buildings frequently stray from the idealised concept of regularity, with discrepancies or inconsistencies in height or planar orientations. Under dynamic stresses such as wind or earthquake, these structures exhibit tensional behaviour due to increased modes of vibration. Transient analysis is done on three-dimensional building frames having stiffness inconsistencies in plan and height while subjected to seismic loading. The torsional response of irregular layouts is evaluated using modifications in natural period, base shear, roof deflection, roof rotation, and storey drift. Soft floors near the base, along with in-plan stiffness eccentricity, have the most negative impact on seismic behaviour.

S. Naveen Ea, N. Mariam, et al. (2018) The structural stability of buildings is usually determined by their layout, which frequently includes a mix of imperfections to improve both functioning and beauty. They investigated strategies to reduce seismic impacts on reinforced concrete structures using conventional frame. They changed a G + 9-story structure by adding protrusions in both plan and elevation, yielding 34 variants with single protrusions and 20 combinations with multiple protrusions. Normal and 54 unusual arrangements were compared, with different plant sizes taken into account. Notably, abnormalities have a substantial influence on earthquake reactions. The study discovered that configurations with a mix of masses, stiffness, and vertical geometric irregularities elicited the strongest responses. Furthermore, the findings highlighted the need of accounting for inconsistencies in structural design to optimize seismic performance.

Resmi Vinod and Nimiya R. Joshuva (2018) investigated the influence of many compartments and compartment widths on seismic analysis behaviour using SAP 2000 model analysis, failure mode analysis, and response spectrum analysis. They found that increasing the number and breadth of compartments resulted in longer time periods for structural reactions. Larger compartments and widths further enhanced the base shift of the operating point. Torsion translation was found as the primary failure mode, with major damage centred in tower sections due to stiffness, strength, and mass changes.

Milind V. Mohod and Nikita A. Karwa (2014): Their analytical research centred on creating buildings using a variety of geometries. The analysis results, which included maximum story displacement and drift, influenced the revision of seismic code regulations for vertical geometric anomalies. The findings provided appropriate critical coefficient values to fulfil the IS 1893 requirements for irregular structures. The study emphasised the importance of accurate analytical methods for assessing seismic features and establishing tougher design restrictions for structures with lower seismic properties.

Firoja Alam and Shree Prakash (2017): Alam and Prakash studied asymmetric multi-story structures, observing higher shear forces and steel reinforcement in columns owing to torsion. Setback buildings, which are distinguished by abrupt decreases in floor area and bulk, have different basic phases than regular structures. The ETABS software examination indicated varying durations among buildings with identical height and width, attributed to irregularity levels.

S. Abdul Rahman and Ansari U. Salik (2016): Rahman and Salik investigated the response of irregular structures to seismic stresses, with an emphasis on earthquake-resistant design. They investigated the proportionate distribution of lateral stresses caused by variations in mass and stiffness across each level of vertically uneven structures. Notably, inconsistencies in mass distribution resulted in sudden changes in floor displacement and drift coefficients, emphasising the need of taking irregularities into account when designing seismic structures for safety.

3. Approach and methodology:

- **Selection of Irregular Forms:** To illustrate various geometric defects, we choose common irregular forms seen in current architecture designs.

- **Structural Modelling:** Advanced modelling software is used to construct detailed structural models of any irregular shape, correctly representing its geometrical qualities and material properties.

- **Numerical Analysis:** We use modal and time history studies to explore dynamic characteristics and seismic response. Modal analysis identifies natural frequencies and mode forms, whereas time history analysis simulates seismic loading effects.

- **Parameter Variation:** Key parameters such as irregularity severity and orientation are modified to see how they affect structure responses, allowing for the discovery of influential irregularity variables.

- **Evaluation of Structural reactions:** Various reactions, including base shear, roof displacement, and drift, are analysed to understand the structures' behaviour during seismic loading.

- **Data Analysis and Interpretation**: Numerical analyses are used to establish meaningful conclusions regarding seismic behaviour, which informs robust infrastructure design.

4.Conclusion:

Seismic Behaviour Comparison: We conducted a complete numerical study to compare the seismic behaviour of structures with planar flaws to their rectangular equivalents.

Distinctive Patterns: Our findings show that buildings with planar defects display different seismic behaviour patterns than rectangular structures. Irregularity severity, distribution, and direction have a substantial impact on structural responses.

Complex reactions: While rectangular buildings may behave more predictably under seismic loads, structures with planar defects frequently exhibit complex and nonlinear reactions, needing careful design and mitigating techniques.

Importance of Incorporating Irregularities: The study emphasises the significance of incorporating irregularities into structural design to improve infrastructure resistance to seismic disasters. Understanding the relationship between structural geometry and seismic reactions is critical for creating successful design guidelines.

Validation and dependability: By validating our findings against experimental data and existing literature, we assure their dependability and allow for more informed decision-making in infrastructure development.

Advancing Knowledge: This study adds to our understanding of seismic behaviour in buildings with planar flaws and emphasises the necessity for ongoing research and collaboration to create novel methods for limiting seismic hazards in infrastructure.

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