Impact of Seismic Zones on the Structural Design of Highrise Buildings for Rectangular and C-Section

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Abstract -
Earthquakes induce vibrations in structures, causing motion in horizontal and vertical directions, with horizontal shaking being predominant. Proper consideration of lateral loads due to earthquakes is essential for designing earthquake-resistant reinforced concrete (RC) structures, especially high-rise buildings. This study analyses the behaviour of a G+15 multi-storied RC building with a consistent story height of 3 meters, subjected to earthquake loads, using response spectrum analysis as per IS 1893 (Part-1): 2016. The seismic performance is evaluated for four seismic zones (II, III, IV, and V) using the ETABS software. Key parameters analysed include bending moment, shear force, lateral displacement, story shear, and story drift. Comparative results highlight the effects of varying seismic zone factors. The findings contribute to understanding structural behaviour under seismic conditions and optimizing designs for enhanced safety and performance in earthquake-prone regions.

Keywords: Earthquake-resistant design, Seismic analysis, Response spectrum analysis, Reinforced concrete (RC) buildings, Seismic zones, ETABS, IS 1893 (Part-1): 2016.

1.INTRODUCTION

The growing demand for tall buildings driven by urbanization and population growth underscores the critical importance of seismic analysis in reinforced concrete (RC) structures. Earthquakes, characterized by random and unpredictable forces, present a significant threat to structural integrity, especially in high-rise buildings. Seismic design emphasizes a balance between safety and economic feasibility, allowing structures to sustain controlled damage while preventing collapse.

Key principles of seismic design include ensuring ductility, stiffness, and energy dissipation during extreme events. Structures are expected to endure minor earthquakes without damage, moderate earthquakes with reparable damage, and severe earthquakes without collapse, as outlined in IS 1893 (Part-1): 2016onse of a building depends on factors such as mass, stiffness, foundation type, and damping characteristics. Essential cons signing for serviceability, damage control, and survival limit states to safeguard critical structures like hospitals and power plants.

India's seismic zoning, Revis the latest IS 1893 code, reflects varying earthquake intensities and design ground accelerations. Advanced software tools, such as ETABS, facilitated analysis of multi-storied buildings, considering parameters like lateral displacement, story drift, and base shear. The engineering approach involves both linear analysis for initial denar methods to assess performance under strong earthquakes.

earthquake-resistant design, importance factors and response reduction factors account for a building's role in the community and its ability to redistribute loads effectively. These considerations ensure life safety, minimize economic loss, and support recovery after seismic events . Through innovative design and strict adherence to codes, engineers can create resilient and the complexities of seismic forces.

1.2 Necessity of the Project

Seismic analysis is a critical component of structural analysis, focusing on assessing the response of buildings and non-building structures to earthquakes. This analysis is integral to structural design, earthquake engineering, and retrofitting efforts in earthquake-prone regions. Ensuring the safety and resilience of structures during seismic events is paramount, as earthquakes can lead to catastrophic damage, threatening lives and property.

Buildings subjected to earthquakes often exhibit oscillatory behavior, known as seismic response, where the structure "waves" back and forth. This movement, primarily in the fundamental mode (lowest frequency), can cause significant damage. Higher modes of vibration may also be activated during seismic events, further influencing the structure's performance. To mitigate the adverse effects of earthquakes, buildings must possess key attributes, including:

1. **Simple and Regular Configuration**: Minimizing irregularities in design reduces stress concentrations and improves overall performance under seismic loads.
2. **Adequate Lateral Strength**: Ensuring the structure can resist lateral forces generated during an earthquake.
3. **Sufficient Stiffness**: Preventing excessive displacements that could lead to structural instability.
4. **Enhanced Ductility**: Allowing the structure to absorb and dissipate energy through controlled deformations without catastrophic failure.

To achieve these attributes, it is essential to accurately determine seismic loads and design the structure with appropriate dimensions and reinforcements. This project is necessary to evaluate the seismic performance of buildings, optimize their design, and enhance their resilience against earthquake-induced forces. By adhering to these principles, the project aims to contribute to the development of safe and sustainable structures capable of withstanding the complexities of seismic events.

1.3 OBJECTIVES OF THE STUDY

The present work focuses on the following objectives:

1. Model Development: To create multi-story G+15 building models with rectangular and C-shaped geometries using ETABS software.
2. Seismic Analysis: To perform a comprehensive seismic analysis of the developed building models using response spectrum analysis, adhering to the guidelines of IS 1893 (Part-1): 2016.
3. Parameter Evaluation: To evaluate key structural response parameters, including lateral displacement, story drift, story shear, stiffness, and overturning moments, for each building model.
4. Comparative Analysis: To compare the seismic performance of rectangular and C-shaped building geometries across different seismic zones (II, III, IV, and V) as per IS 1893 (Part-1): 2016.

1.4 SCOPE AND LIMITATIONS OF THE STUDY

I. The project investigates the variations in seismic behaviour of RC building models to assess their performance under different conditions.
II. RC framed buildings are initially designed to withstand gravity loads, followed by design considerations for seismic loads.
III. Symmetrical bare-frame building models are analyzed across different seismic zones using response spectrum analysis.
IV. The study evaluates the impact of seismic zone factors on building performance, focusing on zones II, III, IV, and V as specified in IS 1893 (Part-1): 2016.
V. Particular attention is given to understanding and discussing the influence of seismic zone factors on the seismic performance of G+15 building structures.
VI. The modeling, analysis, and design of all primary structural elements for the building models are conducted using the ETABS software, ensuring accuracy and adherence to relevant standards.

2. Methodology

The study involves linear dynamic analysis using the Response Spectrum Method for a G+15 storied reinforced concrete frame building. For the rectangular section, the building, located in Seismic Zone I, has a total height of 45 m with 3 m floor-to-floor spacing. It features 9 bays in the x-direction and 5 bays in the y-direction, with a plan area of 37.05 m × 20.00 m. For the C-section, similar modeling is done in Seismic Zones II, III, IV, and V by omitting certain bays. The analysis uses ETABS, adhering to IS 875 (Part-1 & 2):1987 for dead and live loads, and IS 1893 (Part-1):2016 for earthquake loads.

The gravity loads include external wall load (11.73 kN/m), internal wall load (7.2 kN/m), parapet wall load (3 kN/m), floor load (5.75 kN/m²), and a superimposed load of 1 kN/m². The live load is 3 kN/m² for residential use. Lateral loads are determined using IS 1893, considering a zone factor, medium soil, importance factor of 1.2, and 5% damping for SMRF. Spectral acceleration (Sa/g) is computed for all zones, with load combinations such as 1.5(dl + ll) and 0.9dl + 1.5(rs.x). The analysis ensures structural safety under seismic conditions.

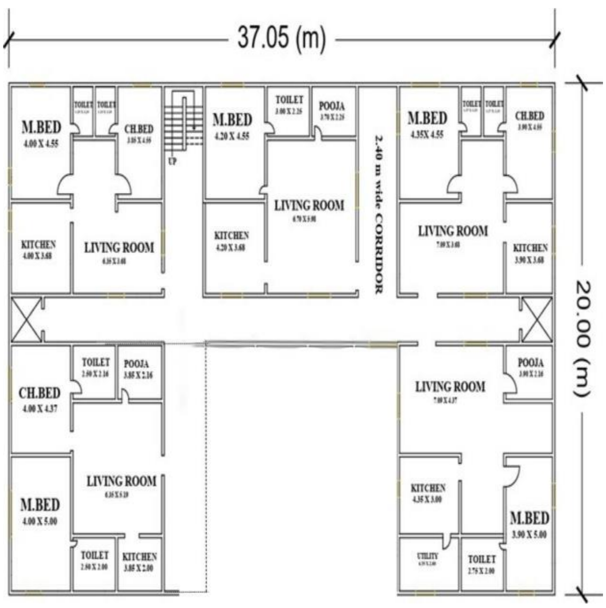
3.RESULT ANALYSIS

3.1 Structural properties used for the model

The building under analysis is a G+15 storied structure with a plan area of 37.05 m by 20.00 m. The floor-to-floor height is 3.00 meters, with columns measuring 750 mm by 750 mm and beams sized 300 mm by 450 mm. The slab thickness is 125 mm. Earthquake loads are calculated as per IS 1893 (Part-1): 2016, and the building is located in Seismic Zones II, III, IV, and V. The live load, including floor finishes, is 3 kN/m², with an additional floor finish load of 1.5 kN/m². The concrete grade used is M30, and the steel grade is Fe500. These specifications ensure the building's structural integrity, with particular attention to seismic safety and load-bearing capacities.

Fig.1.1 C-Section

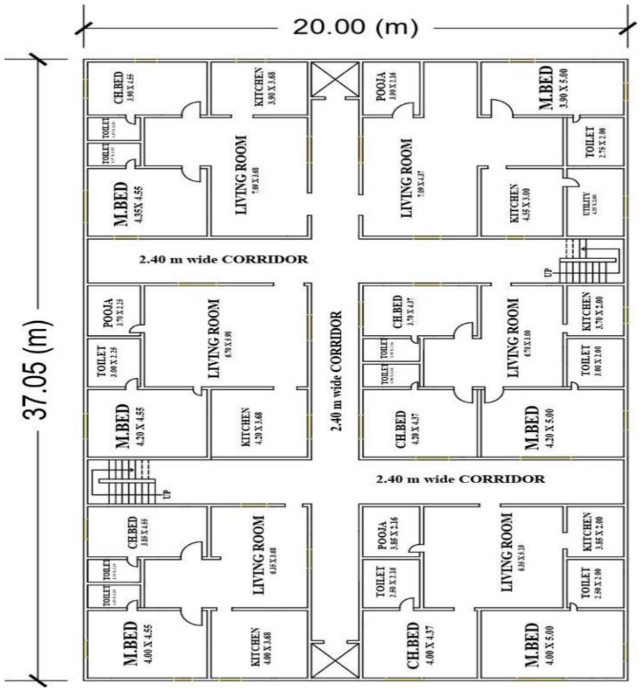
Fig.1.2 Rectangular section



4.Results and Discussion

4.1 For rectangular section

Lateral displacement refers to the horizontal movement



of a story relative to the base of a building during seismic events. As the height of the building increases, lateral displacement tends to grow. Table 5.1 shows lateral displacements in the x-direction for a G+15 building across different seismic zones (II, III, IV, and V). The displacement values increase with storey height, with the highest displacement observed at the top storey. For example, at the 15th storey, the lateral displacement in Zone II is 36.907 mm, while it is 24.604 mm in Zone V, demonstrating the impact of seismic zones on displacement.

The lateral displacement in the y-direction for the G+15 building across various seismic zones (II, III, IV, and V) increases with the storey level. At the ground level, there is no displacement. As the height of the storey increases, displacement grows, with the highest displacement occurring at the top storey (15th storey). For example, in Zone II, the displacement at the 15th storey is 15.179 mm, while in Zone V, it is 54.643 mm. Displacement in the y-direction is notably higher in higher seismic zones, reflecting the increased seismic forces in those regions. The results show a clear correlation between seismic zone and lateral displacement.

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4.2 For C-section

The lateral displacement in the x-direction for the G+15 building across different seismic zones (II, III, IV, and V) increases with the storey height. At the ground level, no displacement is observed. As we move up the building, displacement increases, with the highest displacement at the 15th storey. For instance, in Zone II, the lateral displacement at the 15th storey is 14.803 mm, while in Zone V, it is 53.291 mm. The displacement values are higher in regions with stronger seismic activity (higher zones), showing that seismic forces influence lateral displacement in the x-direction. The results indicate the increasing effect of seismic forces with higher storeys and stronger seismic zones.

The lateral displacement in the y-direction for the G+15 building across different seismic zones (II, III, IV, and V) increases with the storey height. At ground level, there is no displacement, but as the storey level rises, displacement grows. At the 15th storey, the displacement in Zone II is 16.962 mm, in Zone III is 27.139 mm, in Zone IV is 40.708 mm, and in Zone V, it reaches 61.062 mm. These results show that the lateral displacement in the y-direction is significantly influenced by the seismic zone, with higher displacements occurring in regions with stronger seismic activity. The displacement increases progressively as the storey level increases, indicating the building's response to seismic forces.

The storey drift represents the lateral displacement of one floor relative to the floor below it, which is important for the design of partition walls to prevent cracking due to differential movement. According to IS 1893-2002, the storey drift should not exceed 0.004 times the storey height, and according to IS 16700-2017, for earthquake load combinations, it should be limited to hi/250, where hi is the storey height.

The storey drift values for the G+15 building in the x-direction across different seismic zones (II, III, IV, and V) are provided in Table 5.5. The drift values are lower at the ground level and increase with the storey height. For example, at the 15th storey, the drift in Zone II is 0.000120 mm, in Zone III it is 0.000192 mm, in Zone IV it is 0.000288 mm, and in Zone V it is 0.000432 mm. These results show that storey drift increases with seismic zone intensity, with higher displacements in regions with stronger seismic activity.

Among the considered load combinations, "Dl + eq + x" with a partial safety factor of 1 resulted in the highest storey drift values, indicating the significant effect of seismic forces on lateral displacement. The storey drift values are well within the limits specified by the standards, ensuring the building's safety against earthquake-induced forces.

Storey shear refers to the seismic force applied at each floor level, and it is the summation of lateral seismic forces acting at all levels above the storey under consideration. The storey shear values for the G+15 building in the x-direction across different seismic zones (II, III, IV, and V)

At the ground level, the storey shear is zero. As we move up the building, the storey shear decreases with increasing storey levels. For example, at the 15th storey, the storey shear in Zone II is 110.643 kN, in Zone III it is 177.029 kN, in Zone IV it is 232.679 kN, and in Zone V it is 398.315 kN. The results indicate that storey shear is higher in seismic zones with stronger seismic activity (Zone V), and lower in zones with weaker seismic activity (Zone II).

At lower storeys, the storey shear is significantly higher, reflecting the greater accumulation of seismic forces at those levels. As the height of the storey increases, the storey shear decreases due to the distribution of forces across the building. These results demonstrate how seismic forces affect the lateral resistance of the structure, with stronger forces observed in higher seismic zones.

5.Summary and Conclusion

This study analyses the seismic performance of multi-storied buildings with rectangular and C-shaped cross-sections across various seismic zones as per IS 1893 (Part 1): 2016. Key parameters such as lateral displacement, storey drift, storey shear, stiffness, and overturning moments were examined through response spectrum analysis. The findings highlight significant differences in structural behavior between the two configurations under seismic loads.

Rectangular buildings consistently exhibit superior performance due to their symmetrical and uniform design, which ensures even distribution of loads and greater resistance to lateral forces. They show lower lateral displacements, reduced inter-storey drifts, higher stiffness, and lower overturning moments. This predictable behavior enhances stability, making rectangular buildings more suitable for high seismic zones.

Conversely, C-shaped buildings, with their irregular geometry and open sections, experience greater lateral displacements and inter-storey drifts. The asymmetry also leads to reduced stiffness and higher overturning moments, particularly in regions near open ends. While these buildings may offer aesthetic and functional advantages, their performance under seismic forces necessitates additional structural reinforcements, such as shear walls or braces, to address localized stresses and ensure safety.

In summary, rectangular buildings are structurally more efficient and stable under seismic loads, whereas C-shaped buildings require careful design considerations to mitigate vulnerabilities. The study underscores the importance of selecting a building configuration that balances architectural aspirations with seismic safety.

5.1 Scope for Future Study:

- Examine the effect of shear walls at various locations.
- Conduct advanced analyses, such as linear time history or non-linear pushover.
- Use alternative software like SAP2000 or Tekla for comparative studies.
- Explore the impact of different structural irregularities across seismic zones.

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