International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 12 | Dec - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Influence of Mass Irregularities on the Seismic Behavior of Multi-Storied Using STAAD.Pro Connect Edition

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Abstract - The seismic behavior of multi-story buildings is greatly influenced by their structural configuration. Irregularities in plan or elevation, particularly mass irregularities, are critical factors contributing to structural failure during earthquakes. Proper identification and management of such irregularities are essential to optimize a building's functionality and aesthetics.

This study examines the seismic response of a G+14 reinforced concrete (RC) frame structure with and without mass irregularity. The analysis focuses on storey drift, storey displacement, lateral loads, maximum bending moments, and shear forces. A swimming pool placed on the 7th floor introduces a heavy mass, creating mass irregularity as per IS 1893 (Part 1):2016, where a floor's seismic weight exceeds 150% of the floors above and below.

Using STAAD.Pro Connect Edition software, the structures are analysed through dynamic response spectrum analysis. The residential building, with dimensions of 35.45 m × 30.56 m, is subjected to seismic loads according to IS code standards. Results indicate that the inclusion of mass irregularity significantly impacts the seismic response, leading to notable variations in drift, displacement, and internal force distribution.

This study highlights the importance of addressing mass irregularities in seismic design to ensure structural safety and performance in earthquake-prone areas.

Keywords: Mass irregularity, seismic response, RC frame, STAAD.Pro, storey drift, response spectrum, IS 1893:2016, dynamic analysis.

1.INTRODUCTION

Earthquake-Resistant Design: Structural Considerations and Seismic Analysis

Earthquakes are catastrophic events that can lead to severe structural damage and loss of life if not properly addressed in building design. Understanding seismic forces and their impact on structures has improved significantly due to advancements in data collection and modelling technologies [1,2]. These developments provide engineers with tools to create robust designs capable of withstanding dynamic forces.

Structural configuration plays a crucial role in earthquake resilience. Historical seismic events, such as the Bhuj Earthquake in 2001, revealed significant design flaws in irregular structures, emphasizing the importance of regular configurations [3,4]. Uniform distribution of mass, stiffness, and strength across a building's plan and elevation reduces seismic vulnerabilities. In contrast, irregularities, such as re-entrant corners, discontinuous load paths, or uneven stiffness, increase the risk of failure [5,6].

The IS 1893 (Part 1):2016 defines mass irregularity as a condition where a floor's seismic weight exceeds 150% of adjacent floors, making such structures prone to collapse during earthquakes [7]. In this study, a 10th-floor mass anomaly was introduced and analysed using static and dynamic methods to evaluate its impact on structural performance.

Nonlinear dynamic analysis provides an accurate representation of seismic behavior by accounting for time-dependent responses and system nonlinearities [8,9]. It is essential for highly irregular structures, base-isolated designs, or buildings requiring high safety levels [10]. Findings highlight the critical need for uniform structural configurations to mitigate seismic risks.

1.2 OBJECTIVES OF THE STUDY

1. Conduct an analysis of a multi-story building with and without mass irregularity.
2. Evaluate the building's performance under seismic loads in compliance with IS 1893:2016 (Part 1).
3. Examine the response of various building components to seismic forces, comparing regular and irregular mass distributions.
4. Perform Linear Response Spectrum analysis to compare axial loads, displacements, storey drifts, bending moments, and shear forces.

1.3 SCOPE AND LIMITATIONS OF THE STUDY

The study analyses regular and irregular RC-framed buildings (G+14 storeys) with mass irregularity introduced by a swimming pool, located in a seismically active Zone III (moderate seismicity). The contribution of infill walls is considered only as added loads, excluding their interaction with RC frames. Buildings with uneven alignment of infill walls and floor flexibility are not included in the scope. The analysis focuses on understanding the seismic response of these structures, with particular emphasis on the effects of irregular mass distribution. This approach ensures a clear evaluation of structural behavior under dynamic loading conditions, adhering to seismic design standards**.**

2. METHODOLOGY

The seismic analysis of a G+14 RC-framed building with mass irregularity on the 7th floor was conducted using STAAD.Pro Connect Edition software. The study focused on understanding the behavior of a building located in Seismic Zone III (moderate seismicity) under earthquake loads. The structure features mass irregularity caused by a swimming pool, with columns, beams, and walls placed per structural requirements. The Response Spectrum Method, adhering to IS 1893 (Part 1):2016 provisions, was employed for the analysis. The contribution of infill walls was included as additional loads but not considered integral with the RC frame.

The load cases included dead loads (DL), live loads (LL), seismic loads (EL), and roof loads (RF). The self-weights of structural elements, including columns, beams, and slabs, were calculated by the software. Walls and swimming pools were analyzed for their respective weights. Live loads for residential occupancy were set at 3 kN/m², with 25% considered for seismic analysis. The total seismic weight of the building was computed for typical floors and floors with heavy mass, confirming mass irregularity based on IS 1893 (Part 1):2016.

Load combinations used for the analysis were designed to consider seismic effects in multiple directions, including primary horizontal directions and irregular configurations. For regular configurations, combinations such as 1.2[DL+IL+ELX]1.2[DL + IL + EL_X], 1.5[DL+ELZ]1.5[DL + EL_Z], and 0.9DL−1.5ELX0.9DL - 1.5EL_X were applied. For irregular configurations, simultaneous effects of full earthquake load in one direction plus 30% in the other direction were considered, including 1.2[DL+IL+(ELX+0.3ELY)]1.2[DL + IL + (EL_X + 0.3EL_Y)] and 1.5[DL+(ELY+0.3ELX)]1.5[DL + (EL_Y + 0.3EL_X)].

This comprehensive load combination ensured an accurate assessment of bending moments, shear forces, and overall structural performance under seismic conditions. The analysis highlighted the significance of addressing mass irregularities to ensure structural safety and reliability.

3.RESULT ANALYSIS

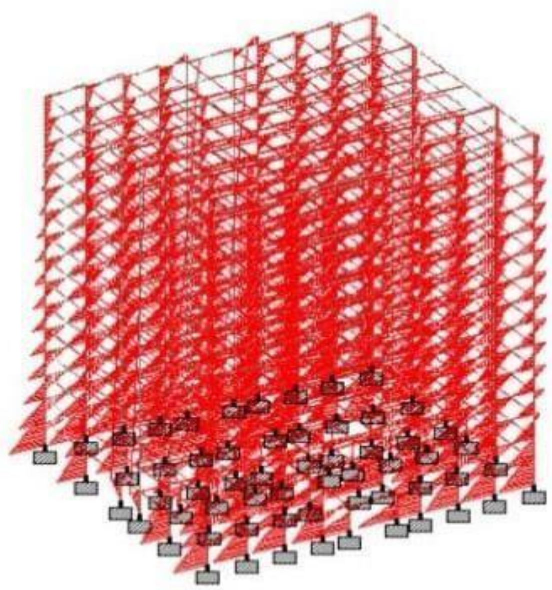

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Fig.1.1 B M D of structure without mass irregularity

bending moments for the beams of the frame 8-A-B-C-D-E-F reveals the effects of mass irregularity introduced at the 7th floor in a G+14 RC-framed structure. The bending moments were compared for cases with and without mass irregularity, as shown below.
In the structure without mass irregularity, the bending moments increased gradually from the 1st to the 9th

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storey, peaking at the 8th floor (243.11 kN-m). A steady decline was observed above this level. However, introducing mass irregularity at the 7th floor significantly altered the distribution of bending moments, particularly at and near the affected storey.

The 7th floor exhibited the highest increase, with bending moments rising from 244.69 kN-m (without mass irregularity) to 346.06 kN-m, marking a notable surge of 41.4%. This increase also impacted adjacent floors, causing slight deviations in the moments at the 6th and 8th floors. The irregularity amplified the bending moments across other storeys by minor percentages, with changes remaining within permissible limits as per IS 456:2000.

The findings emphasize the sensitivity of bending moments to mass irregularities, with the most pronounced effects occurring at and around the irregular floor. This highlights the importance of careful design and consideration of such irregularities to ensure structural stability and compliance with seismic safety standards.

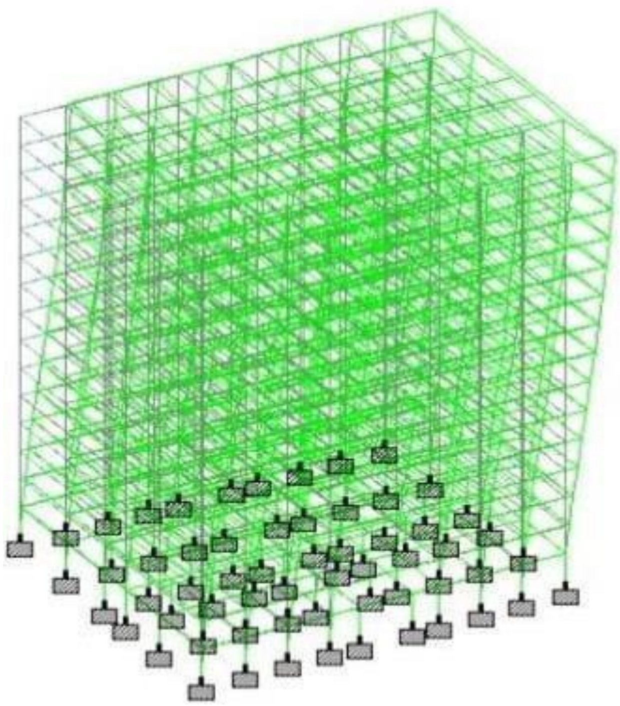

Fig.1.2The movement of a structure without any irregular distribution of mass.

3.1 Maximum Bending Moment

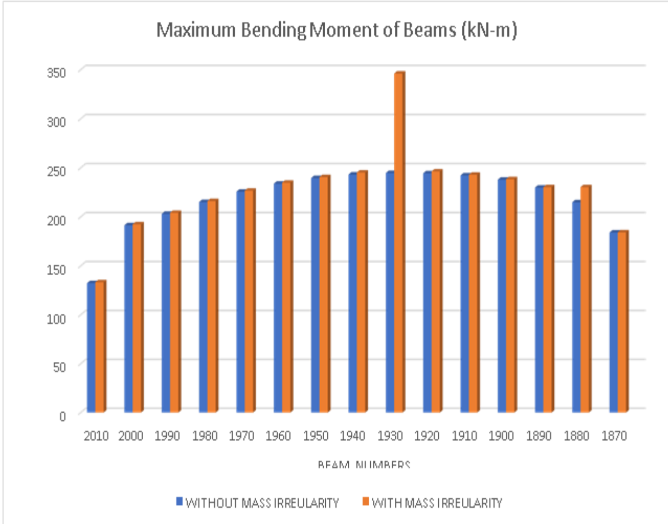

Fig.3 Maximum Bending Moment of the beams of the frame 8-A-B-C-D-E-F fo without mass irregularity and building without irregularity

The analysis of the maximum shear force for the beams of the frame 8-A-B-C-D-E-F reveals the impact of mass irregularity introduced at the 7th floor. The shear forces were compared for the structure both with and without mass irregularity.

Without mass irregularity, the shear forces at the beams increased gradually as we moved from the 1st to the 15th storey, peaking at the 15th storey with a shear force of 82.19 kN. The shear force remained relatively stable with only minor variations from one storey to the next, showing a consistent distribution of forces.

However, when mass irregularity was introduced at the 7th floor, the shear forces were notably altered. The most significant change occurred at the 7th storey, where the shear force increased from 121.06 kN to 213.77 kN, showing a substantial increase of approximately 77%. This increase in shear force at the irregular storey had a cascading effect on the surrounding floors. The shear forces at the 6th and 8th storeys also showed increases, though these were smaller compared to the 7th storey.

For storeys above the 7th floor, shear forces slightly decreased but remained higher than those observed without mass irregularity. This shift in shear distribution highlights the influence of mass irregularity, especially in the vicinity of the affected floor, which can have a considerable effect on the structural performance, potentially leading to higher demands on the structural elements near the irregularity.

This analysis underscores the importance of addressing mass irregularities in design to avoid excessive shear forces that could affect the stability and safety of the structure.

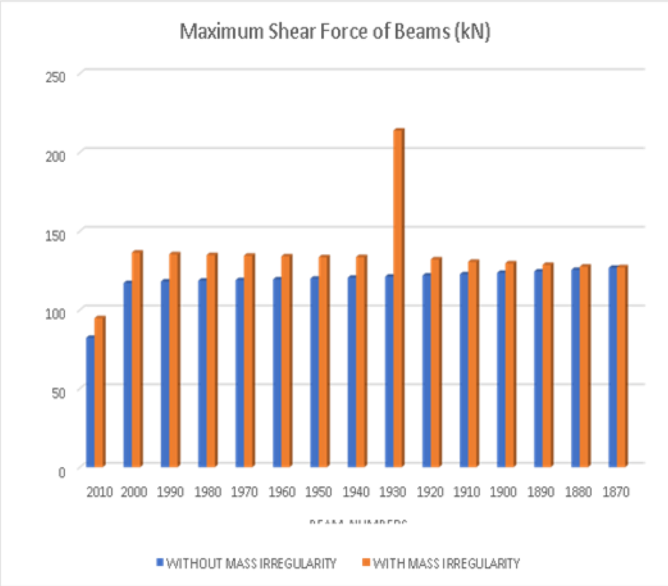

Fig.4Maximum Shear Force of the beams of the frame 8-A-B-C-D-E-F C-D-E-F -f

The maximum bending moment analysis of the columns in the frame 10-A-B-C-D-E-F shows the effect of mass irregularity at the 7th floor on the bending moments throughout the structure. The bending moments were compared for both conditions: without and with mass irregularity.

Without mass irregularity, the bending moments for the columns gradually decreased as we moved from the 15th to the 1st storey. The highest bending moment was observed at the 15th storey (204.83 kN-m), with values progressively reducing towards the ground floor. This shows a typical pattern for a structure without mass irregularity, where the highest moments occur at the top floors.

However, when mass irregularity was introduced at the 7th floor, a noticeable change in the bending moments was observed. The bending moment at the 7th storey increased significantly, rising from 140.13 kN-m to 219.61 kN-m, an increase of nearly 57%. This substantial increase in the bending moment at the 7th storey suggests that the irregularity has a considerable effect on the column forces at that level. Additionally, the bending moments at the 6th and 8th storeys also showed a slight increase, though not as pronounced as at the 7th storey.

For the storeys above the irregularity (i.e., storeys 8 to 15), the bending moments were slightly higher than in the condition without mass irregularity, indicating a redistribution of forces. This pattern demonstrates how mass irregularity at a specific floor can cause local amplifications in the bending moments, particularly in the columns of the affected storey, which could impact the structural integrity and design of the frame.

In conclusion, the introduction of mass irregularity results in significant changes to the bending moments in the columns, particularly at the irregular storey, which should be carefully considered in design and safety evaluations.

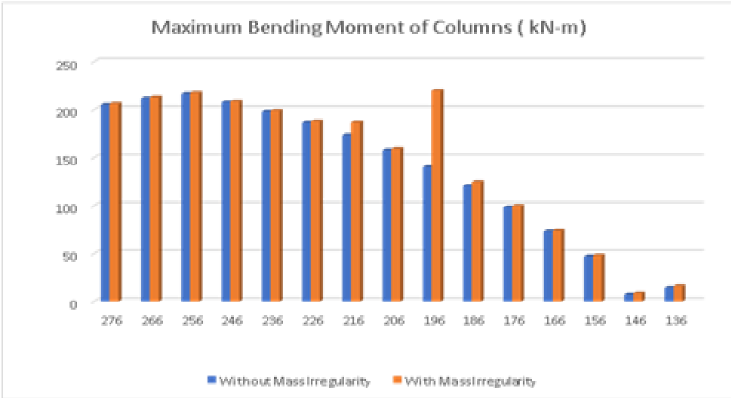

Fig.4Maximum Shear Force of the beams of the frame 8-A-B-C-D-E-F C-D-E-F -f

4.CONCLUSION

The analysis of the frame with and without mass irregularity reveals significant variations in the bending moments, shear forces, displacements, and drifts. In the case of **bending moments in beams**, the irregular model shows an average increase of 1.29% over the regular model across all storeys, with a notable spike of 10.68% at the 7th storey where the irregularity occurs. **Shear forces** in beams remain relatively consistent across storeys, but a marked increase of 11.47% is observed at the 7th storey when irregularity is present.

In the **columns**, both models exhibit typical trends, with bending moments increasing from the top to the bottom of the building. The irregular model shows an average increase of 2.59% compared to the regular model. **Shear forces in columns** also follow a similar pattern but show a 10.05% increase at the 7th storey where the irregularity is introduced. **Storey displacement** in both X and Z directions increases from bottom to top, with the irregular model showing an average increase of 2.1% in the X-direction and 2.97% in the Z-direction. Additionally, **storey drift** increases by an average of 1.52% in the X-direction and 3.67% in the Z-direction for the irregular model.

In conclusion, the presence of mass irregularity leads to higher bending moments, shear forces, and displacements, particularly at the 7th storey where the irregularity is located, which should be taken into account in the design and safety assessments of the structure.

4.1 Further Studies:

Further studies should investigate the impact of different types of irregularities, such as vertical mass irregularity or stiffness irregularity, on the structural behavior of the frame. Additionally, dynamic analysis considering seismic forces and the behavior of the structure under dynamic loading conditions should be conducted to better understand the effects of mass irregularity on overall structural stability. More detailed studies could also explore the effects on other structural elements such as joints, foundations, and overall building performance under extreme loading scenarios.

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