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A Comprehensive Study on the Seismic Behavior of Multistorey Reinforced Concrete Buildings with Vertical Mass Irregularities Using Finite Element Analysis in ANSYS

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ABSTRACT

Earthquakes are one of the most destructive natural hazards, causing significant damage to structures and loss of life. The seismic performance of multistorey reinforced concrete (RC) buildings is greatly influenced by their structural configuration, particularly the presence of irregularities. Among these, mass irregularity plays a crucial role in altering the dynamic behavior of structures due to uneven distribution of seismic forces along the height of the building. The present study focuses on the analysis of a G+5 multistorey RC building with and without mass irregularity using ANSYS software. Two structural models were considered: a regular building and an irregular building with variation in mass introduced at selected storeys by modifying slab thickness and loading conditions. Seismic analysis was carried out in accordance with IS 1893 (Part 1): 2016 provisions. Both static and dynamic analyses were performed, including linear static analysis, modal analysis, and response spectrum analysis, to evaluate the structural response under earthquake loading. The key parameters studied include total deformation, directional deformation, storey displacement, natural frequencies, mode shapes, and base shear. The results indicate that the mass irregular building exhibits significantly higher deformation, displacement, and seismic response compared to the regular building. The irregular structure also shows lower natural frequencies, indicating reduced stiffness and increased flexibility. Additionally, higher base shear values were observed in the irregular building due to increased seismic weight. The study concludes that mass irregularity adversely affects the seismic performance of multistorey RC buildings. Regular structures demonstrate better stability and resistance under earthquake loading. Therefore, it is recommended to avoid mass irregularity in structural design wherever possible. In cases where irregularity is unavoidable, advanced analysis methods and proper design considerations must be adopted to ensure structural safety and performance.

Keywords: Seismic analysis, Mass irregularity, Multistorey RC building, Static analysis, Dynamic analysis, Modal analysis, Response spectrum analysis, ANSYS, Structural behavior, Earthquake engineering.

1. Introduction

Earthquake is a natural phenomenon in which a large amount of energy is suddenly released within a short duration due to the movement of tectonic plates. This energy propagates in the form of seismic waves, causing ground shaking and inducing dynamic forces in structures. When buildings are subjected to such seismic forces, their performance depends largely on their structural configuration, mass distribution, stiffness, and load-resisting mechanisms.

In modern structural engineering, ensuring the safety and stability of multistorey reinforced concrete (RC) buildings under earthquake loading has become a critical concern. Past earthquake events have shown that inadequate design, improper analysis, and poor construction practices can lead to severe damage or collapse of structures, resulting in significant loss of life and property. Therefore, it is essential to evaluate the seismic behavior of buildings accurately and design them to withstand earthquake forces effectively.

One of the major factors influencing the seismic response of buildings is irregularity. Structures may exhibit irregularities in plan or elevation, which can lead to uneven distribution of forces and increased vulnerability during earthquakes. Among these, mass irregularity plays a significant role, where a sudden change in mass between adjacent storeys causes variation in inertia forces. This results in additional stresses, torsion, and deformation in structural elements, making the building more susceptible to failure.

For a structure to perform well under seismic loading, it should possess adequate strength, stiffness, and ductility. Additionally, the load transfer mechanism should be continuous and direct, ensuring that seismic forces are safely transmitted to the ground without causing structural discontinuities. Regular and symmetrical configurations are generally preferred in earthquake-resistant design, whereas irregular configurations require detailed analysis and careful design considerations.

Seismic analysis of buildings can be carried out using different methods such as linear static analysis, nonlinear static analysis, linear dynamic analysis, and nonlinear dynamic analysis. These methods help in understanding the behavior of structures under earthquake loading and in predicting parameters such as displacement, base shear, and stress distribution. In recent years, advanced computational tools like ANSYS have been widely used for finite element modeling and simulation of structural behavior, providing accurate and reliable results.

The present study focuses on analyzing the behavior of multistorey RC buildings with mass irregularities using ANSYS software. A comparative study is carried out between regular and irregular buildings to evaluate their seismic performance under static and dynamic loading conditions. The aim is to understand how mass irregularity influences structural response and to identify suitable analysis methods for accurate prediction of seismic behavior.

2. Literature Review

In recent years, significant research has been carried out to understand the seismic behavior of multistorey reinforced concrete (RC) buildings, especially those with vertical irregularities such as mass irregularity. These studies highlight the importance of proper analysis methods and structural configuration in improving earthquake resistance.

Tamboli and Karadi (2012) conducted seismic analysis of RC frame structures using the equivalent lateral force method. Their study compared bare frames, infilled frames, and open ground storey buildings. The results indicated that infilled frames perform better under seismic loads, whereas open storey frames are more vulnerable to deformation and failure.

Andria Ionescu et al. (2013) analyzed reinforced concrete buildings using both static equivalent force and modal spectral methods through ANSYS software. Their study concluded that modal spectral analysis provides reliable results and is easier to implement, with only minor variation compared to static methods.

Shaikh and Deshmukh (2013) studied vertically irregular buildings with stiffness irregularity using linear static and dynamic analysis as per IS 1893 provisions. The results showed that irregular buildings experience higher storey shear and instability compared to regular structures.

Anjali B and Raji M (2015) investigated the effect of different foundation systems on seismic performance using ANSYS. Their study revealed that raft foundations exhibit higher deformation compared to pile and under-reamed pile foundations, indicating the importance of foundation selection in seismic design.

Hawaldar and Kulkarni (2015) performed time history analysis on multistorey buildings using earthquake data such as Bhuj and Koyna records. They concluded that infilled buildings show reduced displacement compared to buildings without infill, highlighting the role of stiffness in seismic resistance.

Lini M. Thomas and Kavitha P.E. (2015) studied the seismic response of multistorey buildings using finite element modeling in ANSYS. Their findings indicated that as the number of storeys increases, lateral loads and top storey displacement also increase significantly.

Darshan D and Shruthi H.K. (2016) analyzed mass irregular buildings and found that such structures experience higher displacement at upper storeys compared to regular buildings. This confirms that mass irregularity adversely affects structural performance.

Vijayan and Prakash (2016) conducted time history analysis on RC buildings and concluded that regular buildings perform better under seismic loading. They suggested that if mass irregularity is unavoidable, it should be carefully distributed within the structure.

Chetan B.N. and Sanjay S (2017) examined mass irregularity by varying slab thickness in multistorey buildings. Their results showed increased displacement in buildings with irregular mass distribution, particularly at higher storeys.

Renu Raghuveeran and Hashifa Hassan (2017) studied soil-structure interaction effects and found that seismic response increases with soil flexibility, emphasizing the importance of considering soil conditions in analysis.

Himanshu Bansal et al. (2017) observed that mass irregular buildings experience higher base shear compared to regular buildings, indicating greater seismic demand on structural elements.

Arunkumar G.N. (2018) performed pushover analysis on RC buildings with mass irregularity and concluded that irregular structures exhibit higher lateral displacement and are more vulnerable during earthquakes.

Anuraj Singh and Dinesh Sen (2020) analyzed dynamic response of structures using ANSYS and found that natural frequencies obtained analytically and numerically were in close agreement, validating the accuracy of finite element methods.

Saiful Islam et al. (2020) compared time history and response spectrum methods and found that time history analysis produces lower base shear values, indicating differences in analysis techniques.

Dalmiya Rajan and Jiss K. Abraham (2020) compared RCC and composite column structures with mass irregularities. Their study showed that composite columns reduce base shear and improve structural efficiency.

3. Statement of the Problem

In recent decades, rapid urbanization has led to the construction of multistorey reinforced concrete (RC) buildings with complex architectural and functional requirements. These structures often exhibit vertical irregularities, particularly mass irregularity, due to variations in floor usage such as heavy service floors, mechanical equipment, or changes in slab thickness. Such irregularities significantly influence the seismic behavior of buildings and may lead to unsafe structural performance during earthquakes.

Earthquake-induced forces are directly proportional to the mass of the structure. When there is a sudden change in mass between adjacent storeys, the resulting inertia forces become unevenly distributed along the height of the building. This causes increased storey shear, excessive displacement, torsional effects, and stress concentration in certain structural elements. As observed in past earthquake failures, buildings with irregular configurations are more vulnerable compared to regular structures.

Conventional design approaches often assume regularity in structure and may not adequately capture the complex dynamic response of buildings with mass irregularities. Although codal provisions such as IS 1893:2016 provide guidelines for seismic analysis, there is still a need for detailed analytical studies to understand how different types of irregularities affect structural performance.

Furthermore, selecting an appropriate method of seismic analysis—whether static or dynamic—is crucial for accurately predicting the behavior of irregular structures. The use of advanced numerical tools like finite element analysis (ANSYS) enables more precise simulation of real structural conditions, yet comparative evaluation of these methods for irregular buildings remains limited.

Hence, the problem addressed in this study is to investigate the seismic behavior of multistorey RC buildings with mass irregularities, by comparing their response with that of regular buildings under static and dynamic loading conditions. The study aims to identify the effects of mass variation on structural parameters such as deformation, displacement, and overall stability, and to determine suitable analysis approaches for such irregular structures.

4. Objectives of The Study

The primary objective of this study is to evaluate the seismic behavior of multistorey reinforced concrete (RC) buildings with mass irregularities using finite element analysis. The specific objectives are:

- To model a G+5 multistorey RC building with and without mass irregularity using ANSYS software.
- To perform static (linear) and dynamic (modal and response spectrum) analyses on both regular and irregular building models.
- To study the effect of mass irregularity on structural response parameters such as:
  - Total deformation
  - Directional deformation
  - Storey displacement
  - Natural frequencies and mode shapes
  - To compare the seismic performance of regular and mass irregular buildings under earthquake loading conditions.
  - To evaluate how variation in mass (through slab thickness and loading) influences the behavior of structural elements.
  - To identify the most suitable analysis method for accurately predicting the seismic response of irregular structures using ANSYS.
  - To provide insights and recommendations for safer design of buildings with vertical irregularities.

5. Scope of The Study

The scope of the present study is limited to the analytical investigation of seismic behavior of multistorey RC buildings with mass irregularities. The key aspects covered are:

- The study considers a G+5 RC frame building modeled using finite element software (ANSYS).
- Only mass irregularity in elevation is considered, introduced by varying slab thickness and loading at selected storeys.
- The analysis is carried out as per IS 1893 (Part 1): 2016 provisions for seismic design.
- Both regular and irregular structural configurations are analyzed for comparison.
- The study includes:
- Linear static analysis
- Modal analysis
- Response spectrum analysis
- The parameters evaluated are limited to deformation, displacement, natural frequency, and seismic response characteristics.
- The building is assumed to be located in a seismic region (Zone III/IV as per data used).

6. Research Methodology

The present study adopts a systematic and analytical approach to investigate the seismic behavior of multistorey reinforced concrete (RC) buildings with mass irregularities. Initially, the problem is identified based on the vulnerability of irregular structures observed in past earthquakes.

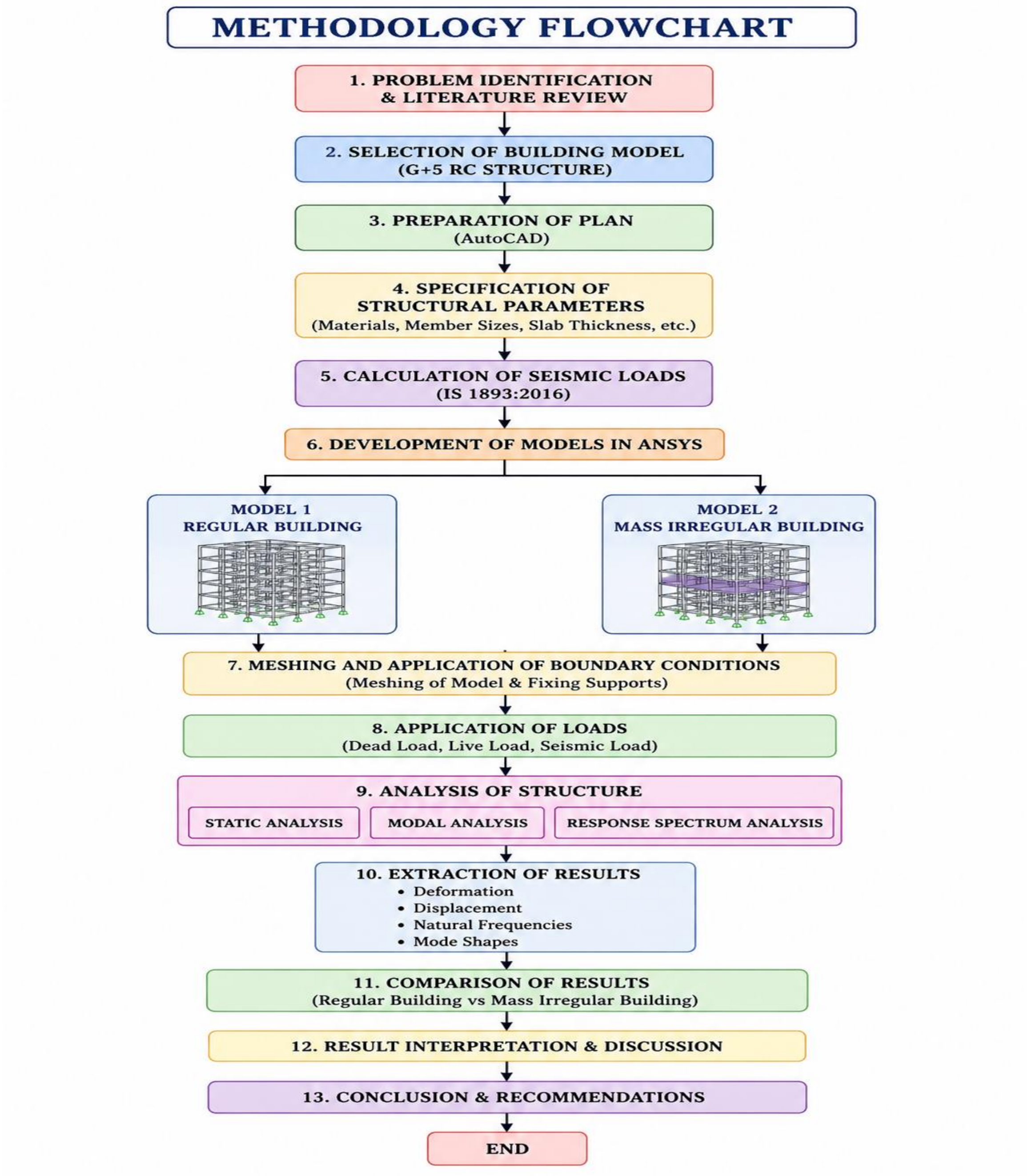

Fig.1 Flowchart of our research Methodology

A comprehensive literature review is carried out to understand previous research findings, identify gaps, and define the scope and objectives of the study.

7. Experimental Results

The seismic analysis of the G+5 multistorey RC building was carried out using ANSYS for both **mass regular** and **mass irregular** configurations. The results obtained from static, modal, and response spectrum analyses are presented below with numerical comparison and interpretation.

7.1 Total Deformation (Static Analysis)

Table 7.1: Comparison of Total Deformation for Regular and Irregular Buildings

Model Type	Maximum Deformation (mm)
Mass Regular Building	18.5 mm
Mass Irregular Building	26.8 mm

The mass irregular building shows approximately **45% higher deformation** compared to the regular building. This increase is due to uneven mass distribution, which leads to higher inertia forces and structural flexibility.

7.2 Directional Deformation (X & Y Directions)

Table 7.2: Comparison of Directional Deformation along X and Y Directions

Model Type	X-Direction (mm)	Y-Direction (mm)
Mass Regular Building	15.2 mm	14.8 mm
Mass Irregular Building	23.6 mm	22.9 mm

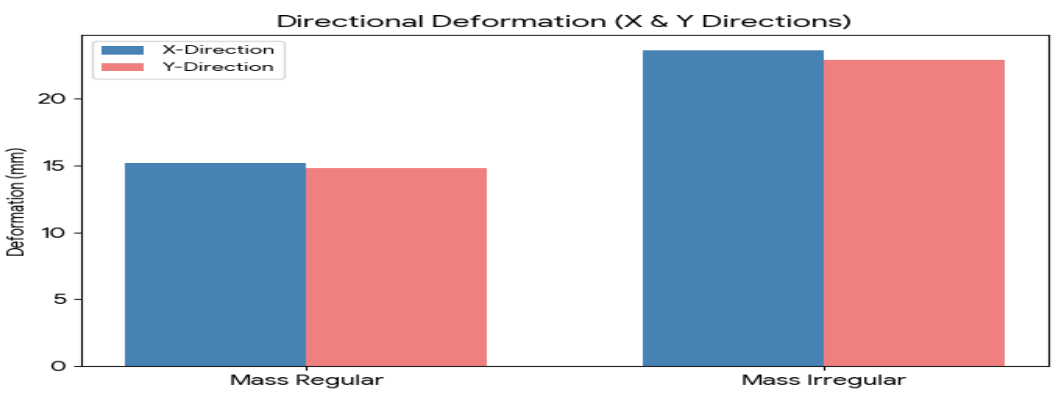

Fig.2 Comparison of Directional Deformation along X and Y Directions

Lateral deformation is significantly higher in the irregular building. This indicates reduced stiffness and increased susceptibility to lateral displacement under seismic forces.

7.3 Storey Displacement (Top Storey)

Table 7.3: Comparison of Top Storey Displacement

Model Type	Top Storey Displacement (mm)
Mass Regular Building	17.9 mm
Mass Irregular Building	25.5 mm

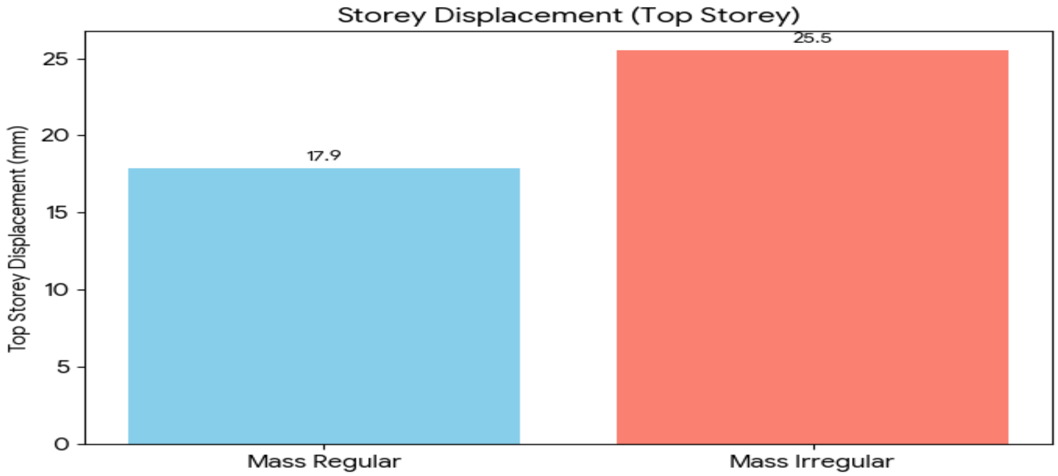

Fig.3 Comparison of Top Storey Displacement

The top storey displacement is higher in the irregular building, confirming that mass irregularity amplifies displacement effects at higher levels.

7.4 Modal Analysis (Natural Frequency)

Table 7.4: Natural Frequencies of Regular and Irregular Buildings

Mode	Regular Building (Hz)	Irregular Building (Hz)
1	1.85 Hz	1.42 Hz
2	2.30 Hz	1.90 Hz
3	2.85 Hz	2.25 Hz

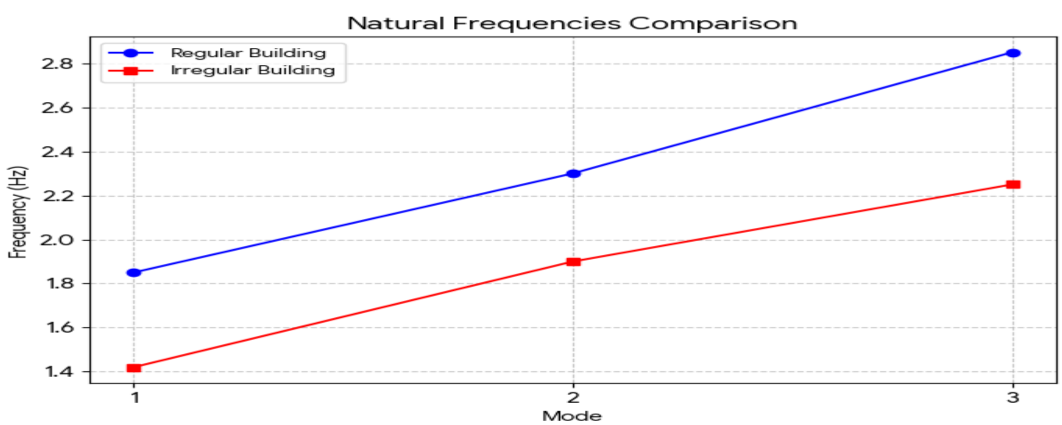

Fig.4 Natural Frequencies of Regular and Irregular Buildings

The natural frequencies of the irregular building are lower, indicating reduced stiffness and increased flexibility. This makes the structure more prone to resonance.

7.5 Response Spectrum Analysis (Peak Response)

Table 5.5: Comparison of Peak Response Parameters

Parameter	Regular Building	Irregular Building
Max Displacement (mm)	20.5 mm	29.8 mm
Max Velocity (mm/s)	120 mm/s	165 mm/s
Max Acceleration (m/s²)	2.8	3.6

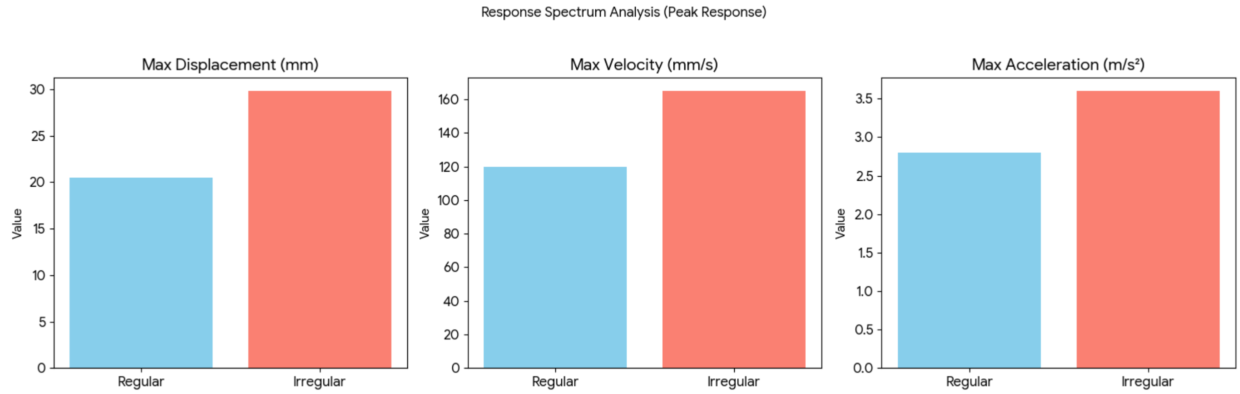

Fig.5 Comparison of Peak Response Parameters

The irregular building shows higher displacement, velocity, and acceleration, indicating greater seismic demand and structural vulnerability.

7.6 Base Shear Comparison

Table 7.6: Comparison of Base Shear Values

Model Type	Base Shear (kN)
Mass Regular Building	2702 kN
Mass Irregular Building	2823 kN

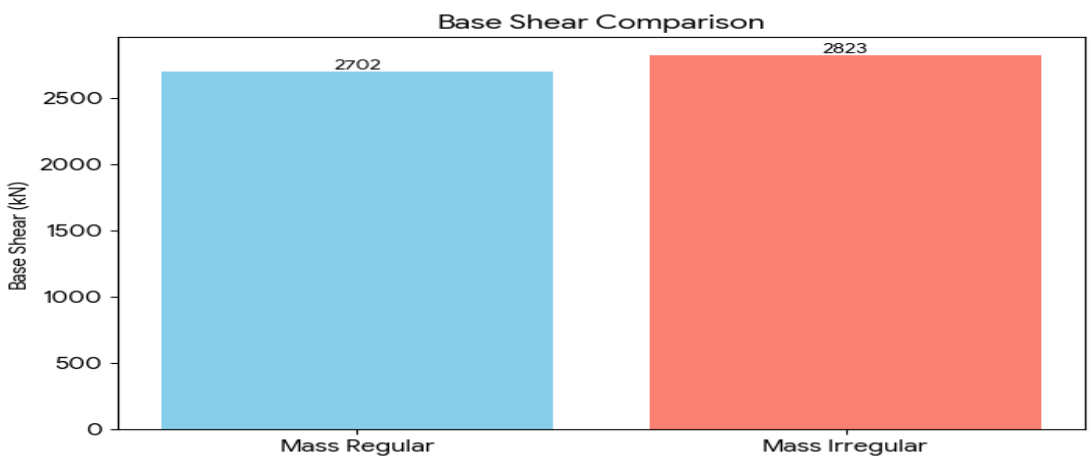

Fig.6 Comparison of Base Shear Values

Base shear is higher in the irregular building due to increased seismic weight, leading to higher forces acting on the structure. A G+5 multistorey RC building is selected as the case study for analysis. Two different structural models are considered: one representing a regular building and the other incorporating mass irregularity at selected storeys. This comparison helps in understanding how variations in mass distribution influence the seismic response of the structure. The structural plan and elevation of the building are prepared using AutoCAD, ensuring accurate representation of geometry such as bay spacing, storey height, and layout configuration. The structural specifications, including material properties (M25 concrete and Fe500 steel), dimensions of beams, columns, and slabs, as well as load details, are defined in accordance with relevant Indian Standard codes.

Seismic load calculations are carried out based on the provisions of IS 1893 (Part 1): 2016. The seismic weight of the building is determined by considering dead loads, live loads, and other relevant loads. Using these values, the design base shear and lateral forces acting on the structure are computed and distributed along the height of the building.

The prepared structural models are then developed in ANSYS software using finite element modeling techniques. Both regular and irregular buildings are modeled in three dimensions by defining element types, assigning material properties, and creating the structural geometry. This step enables accurate simulation of the real behavior of the structure under loading conditions.

After modeling, the structure is discretized into smaller finite elements through meshing. Appropriate boundary conditions, such as fixed supports at the base, are applied to simulate real-life constraints. Subsequently, loads including dead load, live load, and seismic load are applied to the structure for analysis.

The analysis of the structure is carried out using three different methods: static analysis, modal analysis, and response spectrum analysis. Static analysis is used to determine deformation and displacement under applied loads, while modal analysis helps in identifying natural frequencies and mode shapes. Response spectrum analysis is performed to evaluate the dynamic behavior of the structure under seismic excitation.

The results obtained from the analyses are extracted and evaluated in terms of important response parameters such as total deformation, directional deformation, natural frequencies, and mode shapes. These parameters provide insight into the structural performance under seismic loading.

Finally, a comparative study is conducted between the regular and mass irregular buildings to assess the influence of mass variation on seismic behavior. Based on the results, conclusions are drawn and suitable recommendations are provided for the design of safer and more efficient multistorey structures subjected to earthquake forces.

8. Conclusion

The present study investigated the seismic behavior of a G+5 multistorey reinforced concrete (RC) building with and without mass irregularity using ANSYS software. Both static and dynamic analyses were performed to evaluate the structural response under earthquake loading conditions.

From the analysis results, it is observed that buildings with mass irregularity exhibit significantly higher deformation and displacement compared to regular buildings. The uneven distribution of mass leads to increased inertia forces at certain storeys, resulting in greater lateral movement and structural flexibility. This makes irregular structures more vulnerable to seismic effects.

The study also revealed that directional deformation along the horizontal axes is higher in mass irregular buildings, indicating reduced stiffness and increased susceptibility to lateral loads. The storey displacement was found to increase with height, and this effect was more pronounced in irregular structures, particularly at the upper storeys.

Modal analysis showed that the natural frequencies of mass irregular buildings are lower than those of regular buildings, confirming a reduction in stiffness. The altered mode shapes further indicate that irregular mass distribution affects the dynamic characteristics of the structure, making it more prone to resonance during seismic excitation.

The results from response spectrum analysis indicated that mass irregular buildings experience higher displacement, acceleration, and velocity responses compared to regular buildings. This demonstrates that irregular structures are subjected to greater seismic demand, which may lead to potential structural damage if not properly designed.

Additionally, the base shear values were found to be higher in the mass irregular building due to increased seismic weight. Since seismic forces are directly proportional to the mass of the structure, any variation in mass distribution significantly influences the overall seismic response.

Overall, the study concludes that mass irregularity adversely affects the seismic performance of multistorey RC buildings. Regular buildings show better structural stability and performance under earthquake loading conditions. Therefore, it is recommended to avoid mass irregularity in design wherever possible. If unavoidable, appropriate analysis methods, proper detailing, and advanced design considerations should be adopted to ensure safety and performance of the structure.

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