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Analytical Study on Dynamic Characteristics of Mass Irregular Structures under Seismic Excitation

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Abstract

Earthquake-induced structural failures in multistorey buildings are often associated with irregular distribution of mass, stiffness, and geometry. Among these, vertical mass irregularity significantly influences the seismic response and dynamic behaviour of reinforced concrete (RC) structures. This study investigates the seismic performance of a G+5 multistorey RC building with and without vertical mass irregularities using Finite Element Method (FEM) based modelling in ANSYS software.

The analysis is carried out in accordance with IS 1893 (Part 1): 2016 provisions. Two structural models are considered: a regular RC frame building and a vertically mass-irregular building with increased slab thickness and additional floor loads introduced at selected storeys. Static and dynamic seismic analyses are performed to evaluate structural parameters such as total deformation, directional deformation, natural frequencies, mode shapes, and seismic response characteristics.

The study compares the behaviour of regular and irregular structures under earthquake loading conditions. Results indicate that mass irregularity increases lateral displacement, alters modal characteristics, and affects the overall seismic stability of the structure. The irregular building exhibits higher deformation and seismic vulnerability when compared to the regular configuration. The findings emphasize the importance of proper seismic design, ductile detailing, and accurate modelling techniques in minimizing earthquake-induced structural damage.

This research demonstrates the effectiveness of ANSYS-based finite element modelling for seismic assessment of RC buildings and provides useful insights for the design and analysis of earthquake-resistant multistorey structures with vertical irregularities.

Keywords: Seismic Analysis; Mass Irregularity; Reinforced Concrete Buildings; Multistorey Structures; Earthquake Engineering; Finite Element Method (FEM); ANSYS Software; Response Spectrum Analysis; Dynamic Analysis; Static Analysis; Vertical Irregularity;

1. Introduction

Earthquakes are one of the most destructive natural hazards affecting civil engineering structures worldwide. The seismic forces generated during earthquakes produce significant lateral loads on buildings, resulting in deformation, structural instability, and in severe cases, collapse. The behaviour of a structure during seismic excitation primarily depends on its mass distribution, stiffness, geometry, ductility, and structural configuration. Buildings with irregular distribution of mass and stiffness are more vulnerable to earthquake damage when compared to regular structures.

In modern urban development, multistorey reinforced concrete (RC) buildings frequently incorporate architectural and functional irregularities such as setbacks, floating columns, soft storeys, and uneven mass distribution. Among these irregularities, vertical mass irregularity plays a major role in altering the seismic behaviour of buildings. Mass irregularity occurs when the seismic weight of one floor significantly differs from adjacent floors due to increased slab thickness, heavy mechanical equipment, storage facilities, or architectural modifications. Such irregularities create discontinuity in the load transfer path and lead to concentration of stresses during earthquake loading.

The seismic performance of structures with mass irregularity has become an important area of research in earthquake engineering. During seismic excitation, irregular buildings experience higher torsional effects, increased lateral displacement, and uneven distribution of internal forces. These factors may reduce the overall stability and safety of the structure. Therefore, proper seismic analysis and design of irregular buildings are essential to minimize structural damage and ensure life safety. The Indian Standard Code IS 1893 (Part 1): 2016 provides guidelines for seismic analysis and design of buildings considering various structural irregularities.

Various analytical methods are available for evaluating the seismic response of structures, including equivalent static analysis, response spectrum analysis, and nonlinear dynamic analysis. Among these methods, finite element analysis provides accurate prediction of structural behaviour under earthquake loading. Advanced software tools such as ANSYS enable detailed

modelling and simulation of multistorey RC structures for evaluating deformation, stress distribution, natural frequencies, and mode shapes.

The present study focuses on the seismic analysis of a G+5 reinforced concrete building with vertical mass irregularities using ANSYS finite element software. Both regular and irregular structural models are analysed and compared under static and dynamic loading conditions. The analysis includes evaluation of total deformation, directional deformation, natural frequencies, and modal behaviour of the structures. The study aims to understand the influence of mass irregularity on seismic performance and to identify the behaviour of irregular buildings under earthquake excitation.

The outcomes of this research are expected to provide valuable insights into the seismic behaviour of irregular RC buildings and contribute to the development of safer and more efficient earthquake-resistant structural designs.

2.Literature Review

Several researchers have investigated the seismic behaviour of reinforced concrete buildings with structural irregularities. Vertical mass irregularity has been identified as one of the major causes of structural damage during earthquakes because it alters the distribution of inertia forces and dynamic response characteristics of buildings.

Asha Vijayan and Aswathy Prakash (2015) studied the seismic analysis of multistorey reinforced concrete buildings with mass irregularities and reported that irregular structures exhibit higher storey displacement and drift compared to regular buildings. Their study emphasized the importance of dynamic analysis for evaluating the seismic response of irregular structures.

S. Varadharajan, V.K. Sehgal, and B. Saini analyzed the seismic response of RC frames with vertical mass and stiffness irregularities. Their research concluded that irregular distribution of mass significantly affects the modal characteristics and lateral force distribution of buildings under earthquake excitation.

Kevin Shah and Prutha Vyas (2017) investigated the effects of vertical geometric and mass irregularities in structures and observed that buildings with irregularities experience increased seismic vulnerability and require proper ductile detailing for improved earthquake resistance.

Several researchers have also used Finite Element Method (FEM) and ANSYS software for seismic analysis of civil engineering structures. Negru M. and co-researchers performed modal and seismic analysis using finite element techniques and demonstrated the effectiveness of FEM in evaluating structural behaviour under dynamic loading conditions.

Patil and Kumbhar (2013) conducted time-history analysis of multistorey RC buildings under different seismic intensities and concluded that dynamic analysis methods provide more accurate prediction of structural behaviour compared to equivalent static analysis.

The reviewed literature indicates that vertical irregularities considerably influence the seismic performance of buildings. However, the response characteristics depend on factors such as irregularity location, magnitude of mass variation, structural configuration, and analysis method adopted. Therefore, detailed analytical studies are required for better understanding of seismic behaviour in irregular buildings.

3. Background of the Study

Rapid urbanization and increasing demand for multistorey buildings have resulted in the construction of structurally complex buildings with irregular configurations. In earthquake-prone regions, these irregularities significantly influence the seismic behaviour and stability of structures. Among various irregularities, vertical mass irregularity is one of the most critical factors affecting the performance of reinforced concrete buildings during seismic excitation.

Mass irregularity occurs when the seismic weight of one floor differs considerably from adjacent floors due to increased slab thickness, heavy storage loads, mechanical equipment, or architectural modifications. Such variations create discontinuity in mass distribution, resulting in uneven lateral force transfer and stress concentration during earthquakes. Buildings with irregular mass distribution may experience excessive deformation, torsional effects, and structural damage.

Advancements in computational tools and finite element modelling techniques have enabled engineers to accurately simulate the seismic response of structures. ANSYS software provides an effective platform for evaluating deformation, stress distribution, natural frequencies, and modal characteristics of buildings under earthquake loading. This study focuses on analysing the seismic behaviour of a G+5 RC building with vertical mass irregularity using static and dynamic analysis methods based on IS 1893 (Part 1): 2016 guidelines.

4. Research Gap

Although numerous studies have been conducted on seismic analysis of multistorey RC buildings, limited research is available on detailed finite element analysis of vertically mass-irregular buildings using ANSYS software under Indian seismic code provisions. Most previous studies focused mainly on regular structures or considered only simplified analytical approaches. Furthermore, there is insufficient comparative investigation on the influence of varying slab thickness and floor mass distribution on the seismic behaviour of G+5 RC buildings. The effect of mass irregularity location on deformation characteristics, modal response, and seismic stability also requires further investigation.

Hence, there is a need for a comprehensive analytical study using finite element modelling to evaluate the seismic performance of vertically mass-irregular RC buildings and compare their behaviour with regular structures under static and dynamic loading conditions.

5. Objectives of the Study

1. To analyse the seismic behaviour of a G+5 reinforced concrete building using ANSYS finite element software.
2. To study the effect of vertical mass irregularity on the seismic response of multistorey RC buildings.
3. To perform static and dynamic seismic analysis based on IS 1893 (Part 1): 2016 provisions.

4. To evaluate structural parameters such as total deformation, directional deformation, natural frequencies, and mode shapes.
5. To compare the seismic performance of regular and mass-irregular buildings.
6. To identify the influence of irregular mass distribution on structural stability and earthquake resistance.
7. To assess the effectiveness of finite element modelling in predicting seismic behaviour of irregular structures.
8. To provide recommendations for improving earthquake-resistant design of multistorey RC buildings with vertical irregularities.

6. Experimental Design

The present study focuses on evaluating the seismic behaviour of reinforced concrete multistorey buildings with vertical mass irregularities using Finite Element Method (FEM) based analysis in ANSYS software. The experimental design consists of modelling, seismic load calculation, static and dynamic analysis, and comparison of structural response parameters between regular and irregular buildings.

6.1. Structural Modelling

Two G+5 reinforced concrete building models are considered for the study:

- **Model 1 – Regular Building:**
A regular RC frame building having uniform mass distribution throughout the height.
- **Model 2 – Mass Irregular Building:**
A vertically irregular RC building with increased slab thickness and additional floor loads introduced at selected storeys to create mass irregularity.

The building plan consists of four bays in the X-direction and three bays in the Y-direction with a storey height of 3 m. The irregularity is introduced at selected floors by increasing slab thickness from 180 mm to 300 mm.

6.2. Building Specifications

The structural parameters adopted in the study are summarized below:

Parameter	Specification
Building Type	Office Building
Structure Type	RC Frame Structure
Number of Storeys	G+5
Seismic Zone	Zone III
Location	Chennai
Soil Type	Medium/Stiff Soil
Concrete Grade	M25
Steel Grade	Fe500
Storey Height	3 m
Beam Size	350 mm × 500 mm
Column Size	350 mm × 500 mm
Slab Thickness	180 mm (Regular), 300 mm (Irregular)

6.3. Loading Conditions

The building is analysed according to IS 875 and IS 1893 (Part 1): 2016 standards. The following loads are considered:

Dead Load

- Self-weight of beams, slabs, columns, and walls
- Floor finish load = 1.5 kN/m²

Live Load

- Regular floors = 3 kN/m²
- Mass irregular floors = 7 kN/m²
- Roof load = 1.5 kN/m²

Earthquake Load

Seismic loads are calculated based on IS 1893 (Part 1): 2016 provisions considering:

- Zone factor
- Importance factor
- Response reduction factor
- Soil condition
- Design horizontal seismic coefficient

6.4. Finite Element Modelling

The structural models are developed using ANSYS software. Finite element modelling is carried out by discretizing the building components into suitable finite elements for accurate simulation of structural behaviour.

The modelling process includes:

1. Geometry creation
2. Material property assignment
3. Meshing of structural components
4. Boundary condition application
5. Load application
6. Solution and post-processing

The finite element analysis enables evaluation of stress distribution, deformation characteristics, and modal behaviour of the building under seismic excitation.

6.5. Seismic Analysis Procedure

Two types of seismic analyses are performed:

a) Static Analysis

Equivalent static analysis is conducted to determine:

- Total deformation
- Directional deformation
- Storey displacement
- Structural response under lateral seismic forces

b) Dynamic Analysis

Dynamic analysis is performed using response spectrum and modal analysis methods to evaluate:

- Natural frequencies
- Mode shapes
- Dynamic response characteristics
- Seismic performance of regular and irregular buildings

6.6. Response Parameters Evaluated

The following structural response parameters are analysed and compared:

- Total deformation
- Directional deformation
- Natural frequencies
- Mode shapes
- Seismic base shear
- Dynamic response characteristics
- Structural stability under earthquake loading

6.7. Comparative Evaluation

The obtained results from regular and mass-irregular buildings are compared to identify:

- Influence of mass irregularity on seismic response
- Variation in deformation characteristics
- Change in modal behaviour

7. Overall structural performance under earthquake excitation Experimental Results

The seismic analysis of the G+5 reinforced concrete building models was carried out using ANSYS finite element software to evaluate the behaviour of regular and vertically mass-irregular structures under earthquake loading. Static and dynamic analyses were performed in accordance with IS 1893 (Part 1): 2016 provisions. The obtained results were compared based on deformation characteristics, seismic response, and modal behaviour of the structures.

7.1. Static Analysis Results

The equivalent static analysis was conducted to determine the deformation characteristics and lateral response of the building models under seismic loading.

Total Deformation

The analysis results indicated that the mass-irregular building exhibited higher total deformation compared to the regular building. The increased floor mass at selected storeys resulted in larger lateral displacement due to higher inertia forces generated during earthquake excitation.

The deformation pattern clearly showed concentration of displacement near the irregular storeys, indicating discontinuity in stiffness and mass distribution. The regular structure displayed comparatively uniform deformation throughout the height of the building.

Directional Deformation

Directional deformation in both X and Y directions was analysed. The irregular model showed greater directional displacement because of uneven mass distribution and increased seismic weight at specific floors. The irregularity introduced additional torsional effects and amplified lateral movement in the structure.

Storey Response

The seismic response of the irregular structure was more significant at the storeys where additional mass was introduced. Higher displacement and stress concentration were observed in these regions, which may increase the possibility of structural damage during severe earthquakes.

7.2. Dynamic Analysis Results

Dynamic analysis was performed using modal and response spectrum analysis methods to evaluate the vibration characteristics and seismic behaviour of the building models.

Natural Frequencies

The modal analysis results showed variation in natural frequencies between the regular and irregular structures. The irregular building exhibited lower natural frequencies due to increased seismic mass, indicating reduction in structural stiffness and increased flexibility of the building.

Mode Shapes

The mode shape analysis revealed that the regular building maintained relatively uniform vibration patterns, whereas the mass-irregular building exhibited irregular mode shapes with increased lateral and torsional effects. The irregular distribution of mass significantly altered the dynamic characteristics of the structure.

Seismic Response Characteristics

The response spectrum analysis demonstrated that the irregular building experienced higher seismic response values compared to the regular building. Increased displacement, vibration amplitude, and dynamic instability were observed in the irregular model under earthquake excitation.

The results confirm that vertical mass irregularity adversely affects the seismic performance of multistorey reinforced concrete buildings by increasing deformation and reducing structural stability.

7.3. Comparative Analysis

A comparison between regular and mass-irregular buildings indicates the following observations:

Parameter	Regular Building	Mass-Irregular Building
Total Deformation	Lower	Higher
Directional Displacement	Uniform	Increased
Natural Frequency	Higher	Lower
Mode Shape Behaviour	Stable	Irregular
Seismic Stability	Better	Reduced
Torsional Effects	Minimal	Significant

The comparative study confirms that vertical mass irregularity considerably influences the seismic response of reinforced concrete buildings. Structures with irregular mass distribution are more vulnerable to earthquake-induced deformation and require careful seismic design and ductile detailing.

7.4. Discussion of Results

The finite element analysis carried out using ANSYS software successfully simulated the seismic behaviour of regular and irregular RC buildings. The study demonstrates that:

- Increased floor mass results in higher inertia forces.
- Vertical irregularity causes uneven force distribution.
- Dynamic characteristics are significantly affected by mass discontinuity.
- Irregular buildings exhibit greater vulnerability under seismic loading.

The results emphasize the importance of adopting appropriate seismic analysis methods and proper structural configuration to improve earthquake resistance of multistorey buildings.

8. Conclusion

The present study investigated the seismic behaviour of G+5 reinforced concrete multistorey buildings with vertical mass irregularities using Finite Element Method (FEM) based analysis in ANSYS software. Static and dynamic seismic analyses were carried out in accordance with IS 1893 (Part 1): 2016 provisions to compare the performance of regular and irregular building models under earthquake loading conditions.

The analysis results revealed that vertical mass irregularity significantly influences the seismic response of reinforced concrete structures. Buildings with irregular mass distribution exhibited higher total deformation, increased lateral displacement, and greater torsional effects when compared to regular buildings. The concentration of additional mass at selected storeys increased the inertia forces generated during seismic excitation, resulting in uneven force distribution and reduced structural stability.

Dynamic analysis showed that the natural frequencies and mode shapes of irregular buildings were considerably altered due to variation in floor mass. The mass-irregular structure demonstrated lower natural frequencies and irregular vibration patterns, indicating increased flexibility and vulnerability under earthquake loading. The response spectrum analysis further confirmed that irregular buildings experience higher seismic response and deformation characteristics compared to regular structures.

The finite element modelling performed using ANSYS software proved effective in accurately simulating the structural behaviour of RC buildings subjected to seismic forces. The study highlights the importance of proper seismic analysis, ductile detailing, and uniform mass distribution in improving earthquake resistance of multistorey buildings.

Based on the findings of this research, the following conclusions are drawn:

1. Vertical mass irregularity adversely affects the seismic performance of RC buildings.
2. Irregular buildings experience greater deformation and displacement under earthquake loading.
3. Increased floor mass reduces structural stiffness and alters modal characteristics.
4. Dynamic analysis methods provide more accurate evaluation of seismic behaviour compared to simplified static analysis.
5. Finite element analysis using ANSYS is an effective tool for seismic assessment of irregular structures.
6. Proper seismic design and ductile detailing are essential to reduce earthquake-induced structural damage.

Overall, the study demonstrates that buildings with vertical mass irregularities are more susceptible to seismic effects and therefore require careful analysis and design considerations to ensure structural safety and stability during earthquakes.

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