

Design and Analysis of G+4 Building with Ductile Detailing

Pranjal Maher¹, Amruta Chopde^{1*}, Shubham Paradhe², Shaikh Md Yasin²

Abstract

This study presents the structural design and analysis of a G+4 residential building, with a specific focus on ductile detailing to enhance seismic performance. Ductility plays a crucial role in enabling structures to absorb and dissipate energy during seismic events, thereby minimizing structural damage and improving safety. The project emphasizes key reinforcement strategies such as beam-column junction detailing and confining reinforcement, which are critical to preventing brittle failures and improving overall structural integrity. To ensure a comprehensive evaluation, the project utilizes industry-standard software tools including AutoCAD for architectural planning, ETABS for structural modelling and load analysis, and RCDC for detailed reinforcement and design calculations. The process begins with developing an accurate building layout in AutoCAD, followed by importing the plan into ETABS for three-dimensional modelling. Various loading conditions such as dead loads, live loads, and seismic forces are applied to assess the structural response under realistic scenarios. Special attention is given to the beam-column joint regions, where enhanced reinforcement techniques are employed to effectively transfer loads and improve joint ductility. Through a combination of design optimization and simulation, the study investigates the role of ductile detailing in improving resilience and reducing potential failure points during seismic events. The ultimate objective of this research is to demonstrate how proper ductile design and reinforcement strategies can significantly improve the earthquake resistance of urban buildings. The findings aim to contribute to better structural practices, offering valuable insights for engineers and designers seeking to enhance the safety and sustainability of mid-rise reinforced concrete structures in seismic zones.

Keywords: Ductile detailing, seismic performance, ETABS, RCDC, AutoCAD, reinforced concrete, beam-column joint, confining reinforcement, earthquake-resistant design, structural modelling

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INTRODUCTION

India is located in a seismically active region, making it vulnerable to earthquakes. Major past earthquakes like Bhuj and Killari highlight the need for earthquake-resistant buildings, especially in urban areas. To withstand seismic forces, ductile design is essential, enhancing flexibility and structural strength. Ductile detailing reinforces beam-column connections, improving a building's ability to absorb seismic stress. This project focuses on the design and analysis of a G+4 building with a strong emphasis on ductile detailing to improve safety and reliability. Advanced software tools such as AutoCAD (for architectural and structural drafting), ETABS (for structural analysis under seismic loads), and RCDC (for reinforcement

detailing) are used to ensure a robust seismic design. As per IS 1893 (Part 1): 2016, Seismic Zone 4 is categorized as a high-intensity earthquake zone, requiring buildings to resist strong lateral forces using moment-resisting frames, shear walls, or a combination of both. Ductile detailing plays a crucial role in seismic design by ensuring structures deform plastically instead of failing abruptly. Plastic hinges are designed in beams to absorb seismic energy, while reinforcement techniques like stirrups and ties enhance the strength and ductility of beams and columns. Confinement reinforcement further improves structural stability, preventing collapse. India is divided into five seismic zones based on earthquake risk: Zone 1 (Low Risk), Zone 2 (Moderate Risk), Zone 3 (High Risk), Zone 4 (Very High Risk), and Zone 5 (Extreme Risk), where the most robust earthquake-resistant designs are required. Overall, this project aims to provide valuable insights into seismic-resistant construction, ensuring buildings are both functional and safe for occupants during earthquakes.

AIM AND OBJECTIVES

This study aims to design and analyse a G+4 structure using AutoCAD, ETABS, and RCDC, focusing on seismic impact, ductile detailing, and reinforcement optimization to enhance earthquake resistance and structural stability for safer urban construction.

LITERATURES REVIEW

Sardar *et al.* [1]

Numerous recent studies have investigated the impact of P-Delta effects on structures, particularly in seismic conditions. This paper examines how P-Delta influences the seismic response of structures with varying heights. Nonlinear static analysis (pushover analysis) and nonlinear dynamic analysis (time history analysis) were performed using finite element software to assess this effect. The results demonstrate that P-Delta significantly impacts structural behaviour, particularly affecting the peak amplitude of buildings as their height increases. Furthermore, a comparison was made between the seismic responses of concrete and steel structures, highlighting the differences in how each material type responds to P-Delta effects [1].

Gawande *et al.* [2]

They studied how tall structures have become a remarkable engineering achievement in recent times. However, historical data from past earthquakes has demonstrated that a significant number of these structures are either severely damaged or destroyed due to seismic activity. This underscores the importance of evaluating and analysing the seismic responses of buildings. Earthquakes can inflict substantial damage on structures, making it crucial to conduct seismic studies and design buildings that can withstand such forces. The analysis of structures helps determine the deformations and forces induced by applied loads or ground movements, ensuring that buildings are capable of resisting earthquakes during their design phase. Various methods are available for this analysis, depending on the purpose of the study. In this case, the seismic response of a residential G+7 reinforced cement concrete frame building is analysed using the equivalent static method and STAAD.PRO software, following the guidelines of IS 1893 (Part 1): 2016 [2].

Upadhyay *et al.* [3]

The study investigates the seismic response of six G+15 RCC commercial buildings with different plan shapes (Rectangular, L, I, O, T, U) in seismic zone V using Response Spectrum Analysis in ETABS 2018, in accordance with IS 1893 (Part-1):2016. The analysis reveals that all buildings exceeded the permissible drift limit by 36% and the displacement limit by 96%, indicating significant seismic vulnerability. Irregularly shaped buildings (L, I, T, U) performed worse than regular shapes (Rectangular and O), with the U-shaped building being the most susceptible to seismic forces.

The findings highlight the negative impact of building asymmetry on seismic performance, particularly due to torsional effects and uneven mass distribution. The study stresses the importance of designing buildings with seismic resistance in mind, especially in high seismic zones like Zone V, and

suggests incorporating advanced seismic design features such as shear walls and damping technologies to improve the performance of irregular structures and reduce the risk of collapse [3].

Azhar *et al.* [4]

This project involves the structural analysis and design of a G+4 residential building using ETABS software to analyse loads such as dead, live, and seismic loads. The design follows the IS 456:2000 guidelines for reinforced concrete structures, and AutoCAD software is used for creating plans, elevations, and sections. The main objective is to gain practical experience in architectural planning, structural analysis, and design, enhancing both theoretical and hands-on skills in multi-story building design [4].

Chiluka *et al.* [5]

Reinforced concrete (RC) buildings form the majority of Indian building stocks, but many are designed with non-ductile detailing, making them highly vulnerable to earthquakes. With a low building replacement rate, this poses significant risks to lives, properties, and economic activities. This study evaluates the effectiveness of ductile detailing in reducing seismic collapse risk by analysing a four-storey RC Special Moment Resisting Frame (RC SMRF) using the latest seismic codes. Two models one with ductile detailing and one without are designed and assessed through non-linear static analysis. The comparison is based on pushover curves, hinge behaviour, and failure modes. Additionally, a cost-benefit analysis highlights that the slightly higher initial cost of ductile detailing is justified by significant savings in repair and downtime costs over the building's service life. The findings emphasize the advantages of ductile detailing in terms of safety, stability, and economy [5].

Shajahan *et al.* [6]

They explored that the construction of multi-storey buildings is on the rise due to the growing population and rapid development. This is primarily driven by the scarcity of land with higher demand and lower prices compared to individual houses. To ensure safety, cost-effectiveness, and adherence to standards, it is essential to analyse and design these buildings using advanced software such as ETABS. The analysis of a G+10 Reinforced Cement Concrete (RCC) framed structure in this project involves the consideration and application of live loads, dead loads, seismic loads, and wind loads. The objective is to analyse the structural behaviour and ensure compliance with various design codes and standards. The results of analysis are used to confirm the stability of the structure through examination of the Moment Force Diagrams of Axial force, Shear force, Torsion, and Moment. Additionally, the analysis aids in determining the story drifts, or story displacements. The provision of reinforcement details is also accomplished through the detailing of beams and columns [6].

Yunus *et al.* [7]

They analysed a G+15 RCC framed structure using STAADPRO and ETABS to evaluate seismic performance. Load transfer from slabs to the foundation was assessed, and response spectrum analysis was performed per IS:1893 (Part I). Results showed high stiffness under earthquakes, with a modal participation factor over 75%, ensuring minimal deformation and strong seismic resistance. This study highlights the effectiveness of computational tools in optimizing structural design [7].

Thapa [8]

Thapa has explored, that the architectural design of structures such as schools, offices, and hotels often incorporate asymmetry and plan irregularities, which require careful consideration during seismic analysis and structural design. One such irregularity, the re-entrant corner, is classified as a horizontal irregularity by seismic codes like IS 1893 (Part I): 2002. This study focuses on the analysis and design of a multi-storey office building located in Zone V, which features a re-entrant corner horizontal irregularity. The study includes the preliminary design of the building's structural components and seismic analysis using a numerical model based on IS 1893 (Part I): 2002, implemented in ETABS v20.0.0. Key responses, such as the time period, modal mass participation ratios, and storey drift ratio, are assessed to ensure compliance with the codal requirements. Following the seismic analysis, the design of structural components such as

Table 1. Geometric parameters of model.

| S.N. | Type of structure | SMRF |
|------|----------------------------|------------------------|
| 1 | No. of storeys | G+4 |
| 2 | Overall height of building | 21.6 m |
| 3 | Floor dimensions | 14000 mm×9500 mm |
| 4 | Grade of steel | Fe415 and Fe500 |
| 5 | Grade of concrete | M25 |
| 6 | Column dimensions | 230×600 mm, 230×500 mm |
| 7 | Beam dimensions | 230×600 mm |
| 8 | Slab thickness | 110–170 mm |
| 10 | Shear wall thickness | 150 mm |
| 11 | Extremal wall thickness | 230 mm |
| 12 | Internal wall thickness | 150 mm |
| 13 | Bottom storey height | 1.5 m |
| 14 | Typical storey height | 3.6 m |
| 15 | Support | Fix support |

beams, columns, and slabs is carried out, and the required longitudinal and transverse reinforcement for these components at various floors is compared. case, the seismic response of a residential G+7 reinforced cement concrete frame building is analysed using the equivalent static method and STAAD.PRO software, following the guidelines of IS 1893 (Part 1): 2016 [8].

SYSTEM DEVELOPMENT

This section focuses on the design and analysis of a G+4 building structure using ductile detailing, considering seismic forces as per Zone 4 classification. The study follows relevant design codes and standards to ensure structural stability and safety. The Response Spectrum Method is used for seismic analysis to evaluate the building's behaviour under dynamic loading conditions. The methodology includes mathematical modelling, load calculations, and structural analysis to assess the performance of the structure. Ductile detailing is incorporated to enhance the building's ability to absorb and dissipate seismic energy. This section outlines the design approach, analysis process, and key considerations for ensuring the structural integrity of the building (Table 1) [9].

Load Consideration

The loads which are considered for this analysis are Dead loads, Live loads from IS code 875:2015 and Earthquake loads from IS code 1893:2016.

Dead load: IS code 875 part 1 (Code of practice for design loads: DEAD LOAD):

1. The dead load includes the self-weight of the beam, column and slab.
2. Floor finish = 1.5 kN/m² (page no. 29 IS code 875 part 1)
3. Terrace Live load = 3 kN/m²
4. External wall loads on periphery:

Load calculation,

$$\text{Wall thickness} \times \text{height of wall} \times \text{density}$$

$$\text{Wall thickness} = 0.23 \text{ m}$$

$$\text{Height} = 3.6 \text{ m}$$

$$\text{Density} = 18 \text{ kN/m}^3$$

$$\text{Calculation} = 0.23 \times 3.6 \times 18 = 14.904 \approx 15 \text{ kN/m}^2$$

When,

$$\text{Wall thickness} = 0.15 \text{ m}$$

$$\text{Calculation} = 0.15 \times 3.6 \times 18 = 9.72 \approx 10 \text{ kN/m}^2$$

Live load: IS 875 part 2 (Code of practice for design loads: IMPOSED LOAD):

1. Live load on all floors =2 kN/m²
2. Live load on top floor =3 kN/m²

Earthquake load: IS Code 1893:2016 (Criteria for Earthquake Resistant Design of Structure)

1. Seismic Zone =IV
2. Importance factor =1
3. Response reduction factor, R=5
4. Type of soil = medium soil (type II)

PLAN AND 3D VIEW OF STRUCTURE IN ETABS SOFTWARE

Response Spectrum Method

A response spectrum is like a graph that helps engineers understand how buildings react to earthquakes over time. It shows how different structures respond to shaking, helping predict their movement, speed, and acceleration during an earthquake.

This method, called response spectrum analysis, is commonly used to assess buildings and other structures. By studying these graphs, engineers can design safer buildings that can better withstand earthquakes, ensuring stability and minimizing damage [10]. One model of G+4 storey building is prepared for analysis as following. The plan view and 3D view of RCC framed structure are shown in Figures 1 and 2 respectively.

RESULTS AND DISCUSSION

The provided graph in Figure 3 represents a key structural parameter, such as shear force or overturning moment, across different building levels. The x-axis denotes the floor levels, while the y-axis represents the corresponding values. The trend shows that the highest values occur at the ground floor and gradually decrease as we move up, with minimal values at the terrace level. This behaviour is influenced by several factors. Firstly, load distribution plays a significant role, as seismic forces accumulate

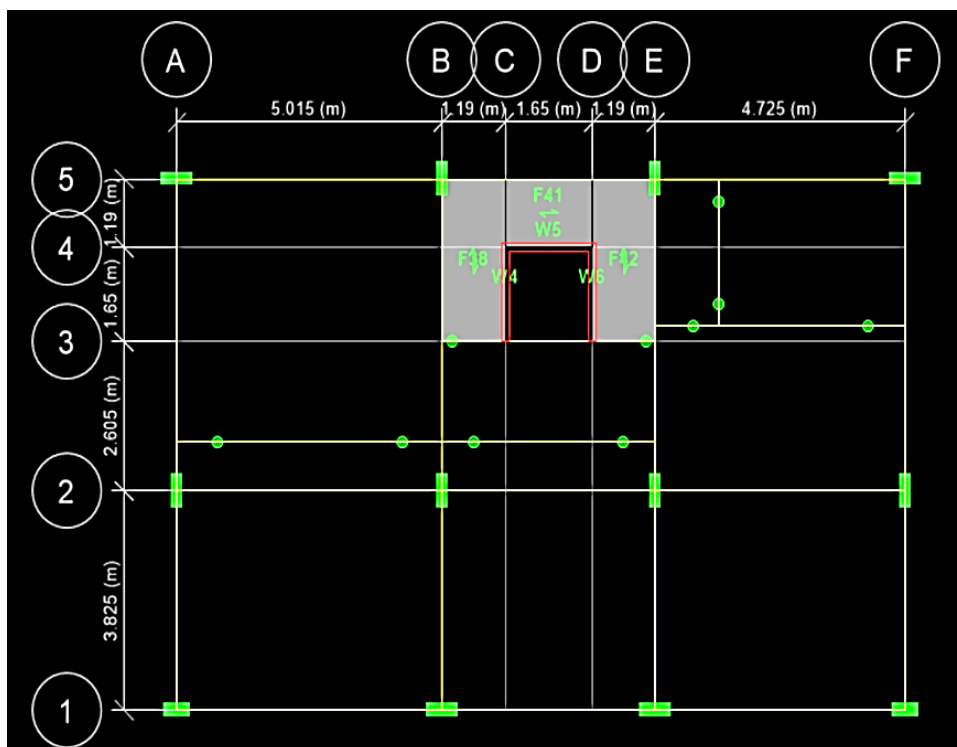


Figure 1. Floor plan of RCC framed structure.

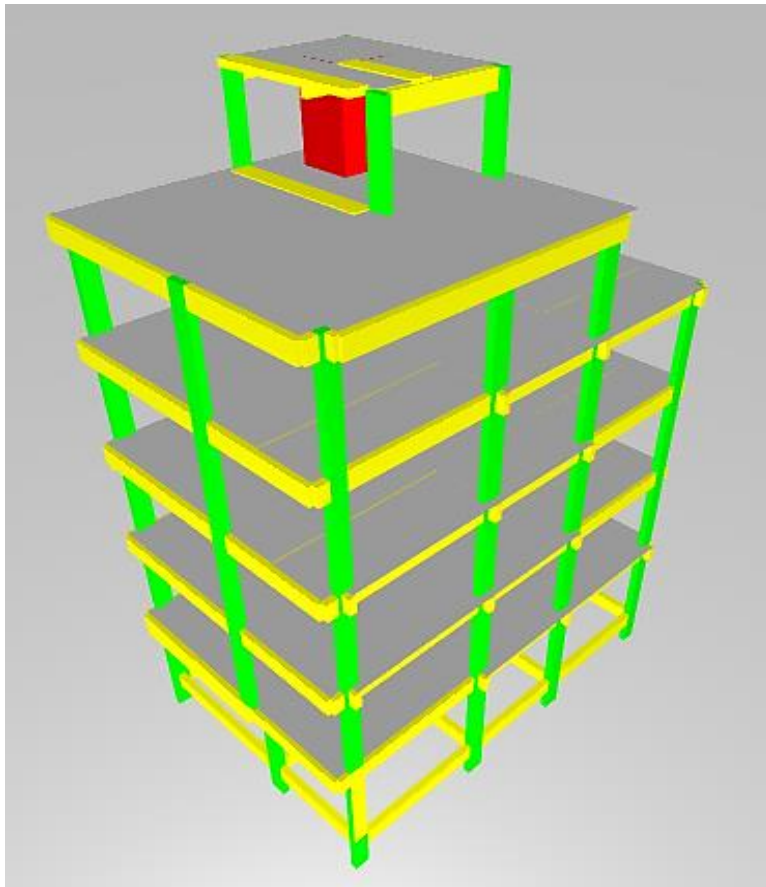


Figure 2. 3D view of RCC framed structure.

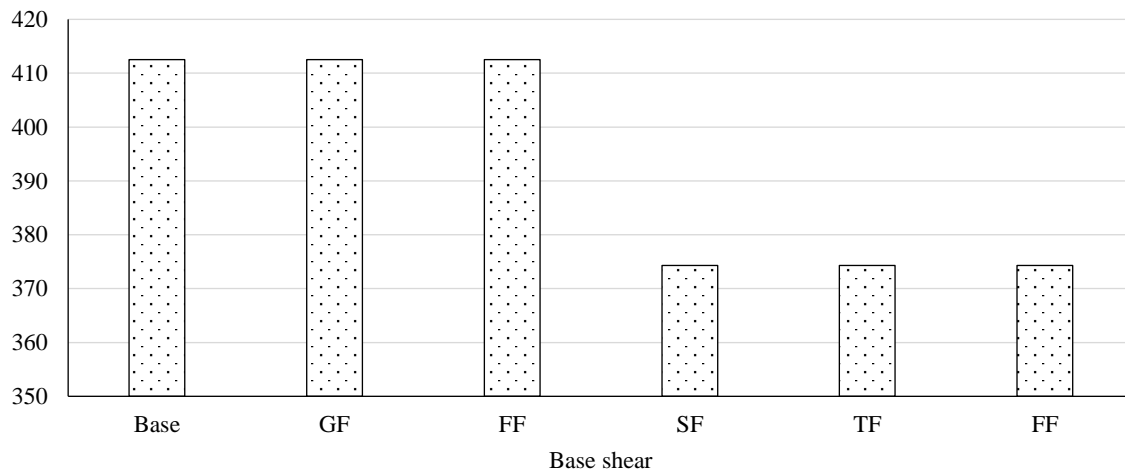


Figure 3. Storey shear.

at the lower levels, which bear the entire structural weight, resulting in higher forces at the ground and first floors. Secondly, structural stiffness affects the response, where lower floors exhibit greater resistance due to direct load transfer to the foundation, leading to force concentration in these areas. Lastly, the diminishing load impact on higher floors reduces the mass contribution as we move upwards, thereby decreasing structural forces, with the least effect observed at the terrace. The results confirm that structural forces are highest at the lower levels and progressively reduce towards the top, emphasizing the necessity for proper reinforcement and ductile detailing at the base and lower floors to enhance seismic resilience and overall structural stability (Figure 3).

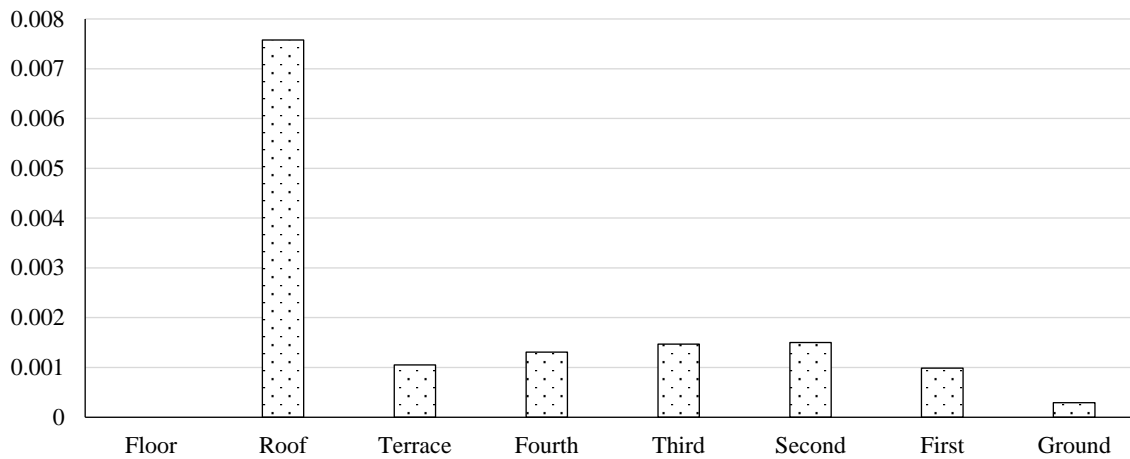


Figure 4. Storey drift.

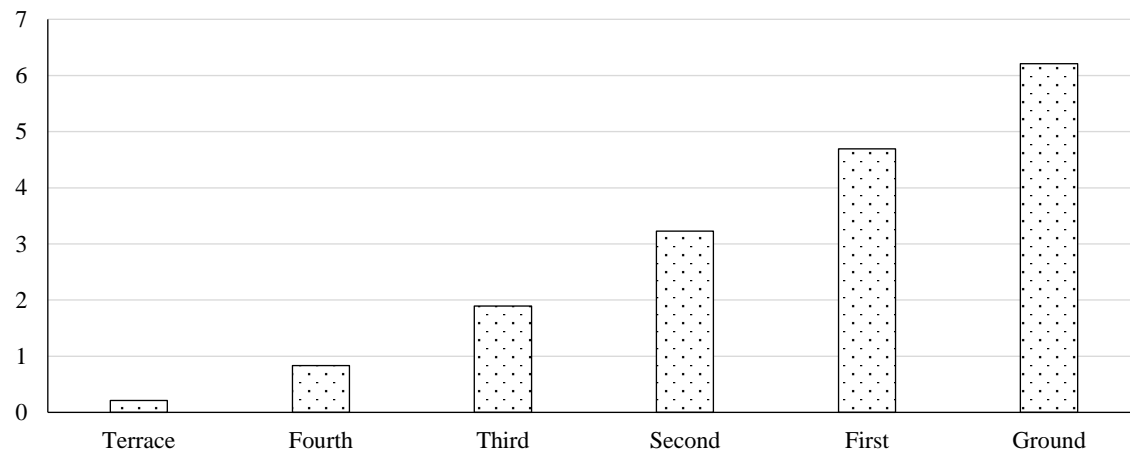


Figure 5. Graph of overturning moment.

The provided graph in Figure 4 illustrates the inter-story drift at different floor levels of the (G+4) building, with the x-axis representing the building floors and the y-axis displaying the drift values. Inter-story drift is a critical parameter in seismic analysis, as it indicates the relative displacement between consecutive floors due to lateral forces. The graph reveals that drift values are lowest at the ground and intermediate floors, gradually increasing as we move upward, with the highest drift observed at the roof level. This trend is characteristic of seismic response behaviour, where the uppermost parts of a structure experience the most significant lateral displacement (Figure 4).

The observed pattern is primarily due to structural flexibility at higher levels, where reduced stiffness allows for greater movement. Additionally, seismic forces accumulate as they travel upward, leading to increased displacement at the top. Conversely, the lower floors, particularly the ground and first floors, have higher stiffness and are constrained by the foundation, which limits their movement and results in lower drift values. These findings emphasize the importance of ductile detailing and lateral stability measures at higher levels to control excessive drift and reduce the risk of structural damage during seismic events.

Overturning Moment

The provided graph in Figure 5 illustrates a key structural parameter (such as shear force, overturning moment, or another response factor) across different building levels. The x-axis represents the floor levels, while the y-axis indicates the corresponding values. The trend shows that the highest values occur at the ground floor, gradually decreasing as we move upward, with the terrace level experiencing

minimal values. This pattern is primarily influenced by the load distribution effect, where seismic forces accumulate at lower levels due to their role in supporting the entire building weight, resulting in higher forces at the ground and first floors. Additionally, structural stiffness plays a crucial role, as the lower floors offer greater resistance and efficiently transfer loads to the foundation, concentrating forces at these levels. As we ascend, the mass and load contribution reduce, leading to progressively lower values at higher floors. The results confirm that structural forces are most significant at the lower levels and decrease toward the top due to mass and stiffness distribution. This highlights the importance of proper reinforcement and ductile detailing at the base and lower floors to enhance structural stability and earthquake resistance (Figure 5).

CONCLUSION

Based on the analysis of the structural parameters, including storey shear, storey drift, and overturning moment, the following key conclusions have been drawn:

1. *Storey shear variation*: The highest storey shear values occur at the ground floor and decrease progressively towards the upper floors, confirming the accumulation of seismic forces at the base of the structure.
2. *Seismic load distribution*: The lower floors bear the highest lateral forces due to their role in transferring loads directly to the foundation, requiring enhanced reinforcement and ductile detailing.
3. *Inter-storey drift trend*: Maximum inter-storey drift is observed at the roof level, while the drift values are lowest at the ground and intermediate floors due to structural stiffness constraints.
4. *Structural flexibility influence*: Higher floors experience greater lateral displacement due to reduced stiffness, emphasizing the importance of lateral stability measures at upper levels.
5. *Overturning moment behaviour*: The overturning moment is highest at the base and decreases as we move upwards, indicating the necessity of a strong foundation and base reinforcement to counteract seismic-induced rotational effects.
6. *Role of structural stiffness*: Lower floors provide greater resistance due to their higher stiffness, concentrating forces at these levels, whereas upper floors are more flexible, leading to increased drift.
7. *Seismic force propagation*: As seismic forces travel upwards, displacement accumulates, necessitating careful detailing to prevent excessive drift and potential structural damage.
8. *Ductile detailing requirement*: Proper reinforcement and ductile detailing at both lower and upper levels are essential to enhance seismic performance and prevent structural failure.
9. *Foundation stability*: The base of the building must be adequately designed to resist overturning moments and ensure overall stability during seismic events.
10. *Earthquake-resistant design considerations*: The results highlight the importance of seismic-resistant design strategies, including the use of flexible structural systems, appropriate damping mechanisms, and energy dissipation techniques.
11. *Regulatory compliance*: The findings align with standard seismic design codes, reinforcing the necessity of adhering to building regulations to ensure safety and durability.
12. *Overall structural performance*: The study confirms that the building exhibits typical seismic response behaviour, and appropriate modifications in design, reinforcement, and detailing can further improve its earthquake resilience.

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