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Earthquake Resistant Analysis and Design of Multistoreyed Residential Building

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Abstract: *Shelter is a fundamental human necessity, and with increasing urbanization and seismic risks, the demand for safe and resilient structures has grown significantly. This project presents the structural analysis, design, and detailing of a multi-storeyed residential building located in the Nashik district, categorized under Seismic Zone III as per Indian standards. Emphasis is placed on earthquake-resistant design using relevant Indian Standard Codes including IS 875, IS 1893 (Part 1): 2016, IS 13920: 1993, and IS 456: 2000, along with design aids and explanatory handbooks such as SP 16, SP 22, SP 24, and SP 34. The structural system was modeled and analyzed using ETABS 2025 (v25), incorporating lateral and gravity loads to ensure stability and serviceability under seismic forces. The project also covers ductile detailing to enhance energy dissipation during seismic events, adhering to modern earthquake engineering principles. The outcome demonstrates a practical application of theoretical knowledge gained during undergraduate studies and highlights the importance of code-compliant design in earthquake-prone regions, contributing to safer infrastructure development..*

Keywords: Earthquake-resistant design, Structural analysis, ETABS, Seismic Zone III, Ductile detailing

I. INTRODUCTION

Shelter has always been one of the primary needs of human beings, offering protection from adverse weather, environmental hazards, and other external threats. In the early stages of civilization, humans relied on natural shelters like caves or built temporary structures using readily available materials such as branches, leaves, and stones. As societies evolved, so did construction techniques, eventually leading to the development of permanent houses made of masonry and concrete. Today, with rapid urbanization and increasing population density, the demand for multi-storeyed buildings has grown significantly, especially in urban and semi-urban areas.

In modern structural engineering, safety, functionality, and sustainability are core principles in designing buildings. Among the most critical challenges in this domain is ensuring the structural stability of buildings under dynamic loading conditions such as earthquakes. Earthquakes are natural phenomena that can lead to catastrophic damage if proper design and detailing measures are not implemented. India, with its vast and diverse geology, is divided into several seismic zones, each demanding a different level of seismic resilience in structures. The Nashik region, where this project is situated, falls under Seismic Zone III, which implies a moderate level of seismic activity that must be addressed through engineering design.

This project focuses on the structural analysis and earthquake-resistant design of a G+11 multi-storeyed residential building in Nashik. Earthquake resistance is achieved by applying ductile detailing principles and conforming to various Indian Standard Codes such as IS 1893 (Part 1): 2016 for seismic design, IS 13920: 1993 for ductile detailing, and IS 456: 2000 for concrete structures. These codes provide comprehensive guidelines on load calculations, member design, and structural behavior under seismic forces. The project integrates these standards into a practical framework for designing a safe and resilient building.

To carry out the analysis and design, ETABS 2025 (v25) software has been used. ETABS is a powerful structural analysis tool widely employed in professional practice due to its ability to accurately simulate complex structural systems and handle various loading conditions. Using ETABS, a three-dimensional model of the building was created, and both gravity loads (dead and live loads) and lateral loads (seismic and wind loads) were applied. The software's analysis capabilities enabled the identification of critical structural members and guided the process of sizing, reinforcing, and detailing structural components such as beams, slabs, columns, and footings.

A key aspect of this project is the incorporation of ductile detailing in the structural members, especially beams and columns, to improve the building's energy dissipation capacity during seismic events. Ductility ensures that the structure can undergo considerable deformation without sudden collapse, allowing it to absorb and dissipate seismic energy. This is particularly important in areas like Nashik, where moderate to strong earthquakes may occur. The project has followed the provisions of IS 13920 rigorously to ensure that the structure will remain safe and serviceable even under seismic duress.

Additionally, this project serves as a bridge between academic knowledge and practical implementation. It translates theoretical concepts learned in structural analysis, RCC design, and earthquake engineering courses into a real-world design task. Beyond using standard codes, various design aids and handbooks such as SP 16, SP 22, and SP 24 were used to streamline the process and validate the outputs from software analysis. The exercise enhances not only technical proficiency but also the understanding of code compliance, professional standards, and safety considerations in building construction.

In conclusion, the project exemplifies how engineering principles can be applied to tackle one of the most pressing challenges in structural design—earthquake resilience. It provides valuable insights into designing a building that not only meets aesthetic and functional requirements but also adheres to the highest safety standards. Through this study, we aim to contribute towards the development of safer infrastructure in earthquake-prone regions like Nashik and empower future engineers with the knowledge and skills required to build responsibly and resiliently.

II. PROBLEM STATEMENT

To design and analyze a multi-storeyed residential building in the seismically active Nashik region (Zone III), ensuring structural safety and earthquake resistance in compliance with relevant Indian Standard Codes.

III. OBJECTIVE

- Reviewing of the available architectural drawing.
- Detailed structural analysis of the building using ETAB2025 v25.
- Design of various structural components.
- Ductile detailing of structural members.
- Acquire knowledge on earthquake engineering.

IV. LITERATURE SURVEY

The structural design of buildings, particularly in seismic zones, necessitates adherence to standard codes and the application of engineering judgment grounded in theory and practice. For this project, various Indian Standard (IS) Codes and supporting literature have been consulted to ensure a reliable and safe design approach.

The **IS 875 (1987)** series provides the foundational guidelines for design loads on buildings and structures. It is divided into five parts addressing dead loads, imposed loads, snow loads, wind loads, and special loads. Part 1 discusses unit weights of building and stored materials, which is essential for dead load calculations. Part 2 emphasizes the imposed loads arising from occupancy and use of the structure. Part 3 focuses on wind loads and includes methods for estimating static and dynamic effects of wind on buildings.

For seismic considerations, **IS 1893 (Part 1): 2016** offers comprehensive criteria for earthquake-resistant design of structures. This code is crucial for structures in Zone III, like Nashik, where earthquake loads govern the lateral design forces. It includes guidance on seismic coefficients, building irregularities, and load combinations relevant for design.

Complementing this, **IS 13920: 1993** prescribes the ductile detailing requirements for reinforced concrete structures.

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The standard aims to enhance the toughness and energy dissipation capacity of RC buildings during earthquakes. It covers detailing methods for flexural members, columns, joints, and shear walls to ensure sufficient ductility.

IS 456: 2000, another essential standard, addresses the design and construction of plain and reinforced concrete structures. It adopts the Limit State Design approach and serves as the baseline code for concrete structures in India, although it is often used alongside IS 13920 for seismic regions.

Several **Special Publications (SP)** released by the Bureau of Indian Standards (BIS) serve as design aids and explanatory handbooks. **SP 16** facilitates faster design using charts and interaction diagrams based on IS 456. **SP 22** and **SP 24** explain the rationale and background behind provisions in IS 1893 and IS 456, respectively, helping to bridge theory with practice. **SP 34** is extensively used for reinforcement detailing, compiling various IS code requirements in a user-friendly format.

In addition to IS codes, several textbooks by renowned authors like **Pillai & Menon**, and **A.K. Jain** have been consulted for RCC design and earthquake engineering. These texts provide both theoretical depth and worked-out examples aligned with Indian Codes. Other supporting literature in structural mechanics and foundation engineering has been valuable for software-based analysis validation and preliminary design checks.

Historical earthquake data, soil conditions, and seismic zoning maps were referenced from government agencies and academic archives. Furthermore, past student project reports provided practical insight into site-specific challenges and common design practices.

VI. METHODOLOGY

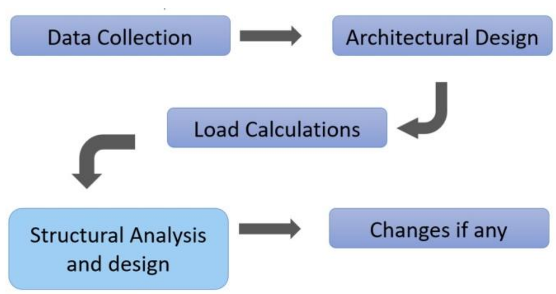

Figure 1: Block Diagram

The methodology adopted for this project involves a systematic approach to the structural analysis, design, and detailing of an earthquake-resistant multi-storeyed residential building. The methodology is broadly divided into several key stages, as outlined below:

A. Review and Understanding of Architectural Drawings

The first step in the project involved a thorough review of the architectural drawings provided for the residential building. These drawings included floor plans, elevations, and sections, which were essential in determining the geometry of the structure, the location of structural elements (beams, columns, slabs, walls), and functional usage of spaces. This information served as a foundation for creating an accurate structural model.

B. Identification of Load Parameters

After understanding the structural layout, the various loads acting on the structure were identified as per IS 875 (Part 1, 2, and 3). These include:

- **Dead Loads**: Calculated using material densities and structural dimensions.
- **Live Loads**: Determined as per occupancy classification.
- **Wind Loads**: Computed considering terrain category, building height, and wind pressure zones.
- **Seismic Loads**: Derived as per IS 1893 (Part 1): 2016, considering the building's location in Seismic Zone III, importance factor, response reduction factor, and soil type.

C. Modeling and Structural Analysis using ETABS

A three-dimensional model of the building was developed using **ETABS 2025 v25**, a structural analysis and design

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software. The following steps were taken:

- Geometry definition including grids, storey levels, and frame members.
- Assigning cross-sectional properties to beams, columns, and slabs.
- Defining load cases and combinations in accordance with IS 875 and IS 1893.
- Performing linear static and response spectrum analysis.
- Identifying critical structural responses including displacements, storey drifts, and internal forces in members.

D. Design of Structural Elements

Based on the analysis results, structural components were designed in compliance with IS 456:2000 and IS 13920:1993 for ductility:

- **Slabs**: Designed as per moment and shear conditions.
- **Beams and Columns**: Designed for combined bending and axial forces using interaction curves and ductility provisions.
- **Footings**: Isolated footing design was performed based on axial loads and soil bearing capacity.
- **Shear Walls (if any)**: Checked for shear capacity and stiffness contribution.

E. Ductile Detailing and Reinforcement

Reinforcement detailing was performed based on IS 13920 to ensure ductile behavior during seismic events. Specific provisions implemented include:

- Adequate anchorage length and confinement in beam-column joints.
- Shear reinforcement and transverse ties in columns.
- Use of detailing aids from SP 34 and SP 16 to facilitate accuracy and efficiency.

F. Manual Cross-Verification

To ensure the correctness of the software-based design, key structural components (a typical slab, beam, and column) were designed manually and cross-verified using SP 16 charts and formulas from IS 456 and IS 1893.

G. Drafting of Structural Drawings

Using AutoCAD or similar drafting tools, structural drawings were prepared to show:

- Beam and slab layouts
- Column positions and footing details
- Reinforcement detailing for various components

H. Documentation and Report Compilation

The final step involved compiling all design calculations, analysis results, structural drawings, code references, and observations into a detailed project report. Literature reviews, methodologies, and conclusions were also included to support academic requirements.

VII. RESULT AND DISCUSSION

The structural analysis and design of the G+11 residential building yielded a comprehensive set of results in terms of displacements, internal forces, reinforcement requirements, and structural safety under both static and dynamic loads. The discussion of the key results is presented below:

A. Structural Analysis Results

The building model was analyzed for various load cases including dead load, live load, wind load, and seismic load using ETABS. The following key outcomes were observed:

- **Storey Displacement**: The maximum lateral displacement under seismic load was within the permissible limits specified in IS 1893:2016. The displacement did not exceed **0.004h** (where *h* is the storey height), indicating adequate lateral stiffness of the structure.
- **Storey Drift**: The inter-storey drift values under seismic loading were also within the allowable limit of **0.004 times the storey height**. The presence of shear walls and proper moment-resisting frames contributed significantly to drift control.

- **Base Shear**: The base shear generated for the building was in accordance with the calculated design base shear from the response spectrum method. Proper distribution of stiffness and mass resulted in a uniform shear profile.

B. Member Forces and Design Checks

- **Beams**: The maximum bending moment and shear forces were recorded at beam mid-spans and supports, respectively. Beams were adequately reinforced based on the calculated moments, and all sections satisfied flexure and shear criteria as per IS 456:2000.
- **Columns**: Critical axial loads and moments were observed at lower storey columns. Design was checked using interaction curves and ductile detailing provisions as per IS 13920:1993. Columns were provided with appropriate lateral ties for confinement.
- **Slabs**: The slabs were designed as two-way slabs with appropriate moment distribution. Deflection checks were carried out and found satisfactory.
- **Footings**: Isolated footings were designed to resist axial loads and moments. Safe bearing capacity was assumed based on soil data. All footings satisfied the one-way and two-way shear checks.

C. Seismic Performance

The structural configuration adopted – a regular frame with symmetrical layout and sufficient lateral load-resisting elements – ensured good seismic performance. Use of ductile detailing provisions enhanced energy dissipation capacity, improving structural resilience under earthquake loading. The response spectrum analysis indicated acceptable vibration characteristics, with the fundamental time period matching the values estimated using IS code formulas.

D. Comparison with Manual Calculations

Manual design was conducted for selected components such as a typical mid-span beam and a central column. The results from manual methods closely matched the ETABS results, validating the accuracy of the model. Minor differences arose due to idealizations in software modeling versus conservative assumptions in manual calculations.

E. Practical Implications

The final design is structurally efficient and conforms to Indian Standard codes. The reinforcement detailing has been optimized for economy without compromising safety. Furthermore, the project demonstrates the practical application of advanced software tools in conjunction with traditional design methods, enhancing both accuracy and efficiency in modern construction practice.

VIII. CONCLUSION

Nashik is located in seismic Zone 3, which necessitates careful consideration of earthquake forces in the structural design to ensure safety, durability, and serviceability. The residential apartment building designed in this project integrates all essential seismic design principles and complies with relevant Indian Standards to effectively resist earthquake-induced forces along with typical gravity loads. The structural system and detailing have been developed to provide adequate ductility and strength, thereby minimizing potential damage during seismic events. This project not only demonstrates the practical application of theoretical knowledge but also highlights the importance of adhering to seismic design codes in earthquake-prone regions. We, as civil engineering students, hope that our work meets the academic expectations and contributes to safer building practices in such areas.

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