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Structural Analysis and Design of Tall Building and Validation Using IS 16700 (2023)

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Abstract: *The population surge in Kerala has spurred the need for innovative construction approaches due to limited space, with urbanization propelling demand. Consequently, the necessity for vertical expansion becomes apparent, driving the construction of tall buildings.*
The project explores into the design challenges and solutions for tall buildings, especially in seismic-prone regions. Focusing on a G+19 residential building in Seismic Zone III, the study adheres to IS 16700:2023 standards. The project outlines a meticulous methodology, incorporating dynamic analyses, validation processes, and ductile detailing for enhanced earthquake resistance.
The design basis report specifies about project specifications, construction materials, structural systems and design criteria. The project progresses with structural general arrangement drawings along with structural modelling and analysis using ETABS. Structural parameters and analysis results are checked against the specifications mentioned in IS 16700:2023 and non-compliant parameters are brought into alignment with specified code requirements. Further, the structure is designed following IS 13920: 2016 and IS 456: 2000. The advancement of project is done by designing and detailing of various structures using RCDC.
The study includes a detailed comparison between the performance of building with and without considering specifications mentioned in IS 16700:2023. Eventhough the former requires high performance construction materials that causes an increase in initial cost, enhanced safety, improved serviceability and potentially lower repair costs outweigh the initial investment.
This comprehensive approach amalgamates advanced technology with stringent adherence to regulatory standards, emphasizing safety and structural integrity. By addressing the challenges of vertical expansion in dense urban environments prone to seismic activity, the project offers invaluable insights into sustainable construction practices, essential for Kerala's evolving urban landscape.

Key Word: *Tall buildings, Seismic zone, Modelling*

I.INTRODUCTION

The population of Kerala has been on a consistent upward trajectory, contributing to one of the highest population densities in India. As urbanization continues, the pressure to accommodate the growing populace intensifies, necessitating innovative approaches in construction and design. With limited available land and the intensifying demand for space, there arises an imperative need for vertical expansion in the construction of buildings. Tall buildings represent a viable solution to address this demand for space efficiently.

The construction of tall buildings presents several challenges. Tall buildings are not merely subjected to vertical loads but are also significantly affected by lateral forces, such as those induced by earthquakes or wind. The stability of such buildings become a major challenge in the earthquake prone areas. Kerala is situated in Seismic Zone – III and all the buildings constructed there needs to undergo dynamic analysis [7]. For buildings with height greater than 50 m, the design standards must conform to [8]. The code covers the design aspects of reinforced concrete (RC) buildings of height greater than 50 m but less than or equal to 250 m. It includes selection of appropriate structural system, geometric proportioning of building, integrity of structural system, resistance to wind and earthquake effects, and other special considerations related to tall buildings.

[1] focused on high-rise building design and analysis using ETABS 18 software, with specific consideration for a 17-storey structure based on [8] guidelines and [7], [10], and [12]. The research also investigated the impact of outrigger systems and shear walls on the structural performance. Specifically, the study considered the provision of shear walls with a response reduction factor of 4, as per [7] and examines the optimal placement of outrigger systems for different building heights. In an outrigger and belt truss system, the core wall primarily serves to handle lateral forces.

[2] examined how bracing systems and base isolation influence the seismic response of high-rise buildings with different vertical irregularities. A 20-story building with vertical irregularities is modeled based on the principles outlined in [7] and [8]. Software like CSI ETABS is used to perform seismic analysis on three types of vertical irregularities: setbacks, open ground stories, and multiple setbacks. The analysis compares the seismic performance of the building in various scenarios: without any earthquake resistance, with X-bracing, and with base isolation. The results indicate that base isolation significantly improves the building's seismic performance. However, as the severity of the vertical irregularity increases, the overall seismic performance

tends to decrease.

[3] investigated high-rise buildings, covering their definition, safety considerations, structural stability, and design challenges. It then explores existing structural systems documented in various sources. The focus is on a prevalent technical issue: selecting an effective structural system to resist lateral loads from wind and earthquakes. [3] provides a general overview of how different structural systems behave in high-rise buildings of varying heights. It is based on analyses using both nonlinear static procedures (pushover) and nonlinear dynamic procedures (for wind and earthquake loading). Finally, the section critically reviews available simplified models and seismic energy base designs. It aims to inform the development and application of future construction systems for high-rise buildings.

[4] conducted a comprehensive analytical study of tall buildings using [8]. Through a combination of linear and non-linear analysis methods, seismic evaluations, and an exploration of stiffness modifiers, the research aims to advance the understanding of tall building behaviour, providing valuable contributions to the field of structural engineering and design.

[5] provided information highlights critical considerations in seismic design and structural engineering, emphasizing the impact of discontinuity in vertical stiffness and strength on building performance during earthquakes. The discussion extends to seismic design practices in different regions. While high-rise buildings with transfer storey configurations are common in low seismicity areas, concerns arise about their performance in rare, major earthquakes. It goes deep into specific provisions in [7], emphasizing restrictions on lateral stiffness differences between consecutive storeys. Notably, the Indian Tall building code permits a maximum stiffness difference of 30%, potentially bypassing certain stiffness irregularity clauses.

[6] examined various considerations and challenges associated with tall buildings, drawing on insights from [8]. It explores how structural configuration and seismic zone influence the selection of the structural system and building layout. The analysis for seismic loads incorporates some modifications compared to [7]. Additionally, the modelling approach for the tall building and any changes made to design considerations are outlined. Furthermore, the criteria for selecting appropriate foundations are presented. It emphasizes the importance of non-structural elements and provides design guidelines based on their sensitivity to seismic events.

In this paper, analysis of tall building was carried out dynamically according to [7]. Structural parameters and results were checked to be in adherence with the specifications of [8] and non-compliant parameters were brought into alignment with the specified code requirements. Design and detailing of tall building was done following [9] and [10]. A comparative analysis was done between the performance of tall buildings designed considering the specifications of [8] and those designed using conventional design practices without considering the specifications of [8]. It was concluded that the design in accordance with [8] may be complicated, requires high grade construction materials and may increase the overall construction cost but it is having several long-term benefits such as enhanced safety, improved serviceability, and potentially lower repair costs after seismic events that outweigh the initial investment.

II.IS 16700 (2023) – CRITERIA FOR STRUCTURAL SAFETY OF TALL CONCRETE BUILDINGS [8]

The increasing urbanization and limited land availability in urban centers are driving the construction of tall buildings to accommodate growing populations. [8] provides a comprehensive guide to address the specific design challenges of reinforced concrete tall buildings. These buildings require considerations beyond just structural safety; they must also ensure serviceability conditions. [8] focuses on reinforced concrete buildings between 50 meters and 250 meters tall, outlining specific design requirements for this building type.

[8] is applicable for tall buildings located at least 10 km (shortest distance) from the near-field of seism genic faults. Buildings located within that zone require a more rigorous approach to design and construction. While the general principles of [8] can be used for these buildings, stricter specifications might be necessary based on client requirements or a local authority's expert committee. [8] can be a valuable resource for designing buildings 50 meters or less in height. However, it's not suitable for buildings exceeding 250 meters. In cases where a building doesn't meet the criteria of [8], a more in-depth design and review process is required.

III.PROBLEM DEFINITION

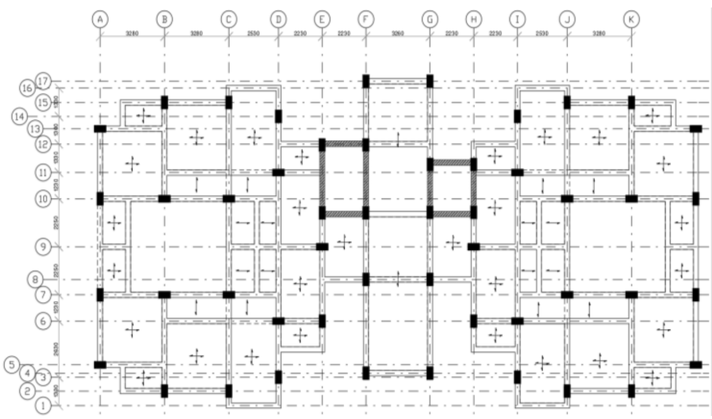

Fig 1. A typical general arrangement of the structure

A RC framed residential building with plan area 30 m x 13.5 m was designed. It has 20 storeys (G+19) with floor-to-floor height equal to 3 m and a total height of 62 m which is greater than 50 m. [8] M30 concrete and HYSD Fe 500 bars were used. [8][9] Shear walls were also provided.

The trial sizes adopted for columns, primary beams, and secondary beams were 320 mm x 600 mm, 250 mm x 550 mm and 250 mm x 350 mm respectively and that of one-way slab, two-way slab and shear wall are 150 mm, 125 mm and 250 mm respectively. Dead loads were calculated according to [12] and live loads were taken from [13]. The seismic considerations were adopted according to [7].

Table 1. Seismic considerations according to [7]

Parameter	Value
Zone factor	0.16
Importance factor	1.2
Response reduction factor	5
Soil type	1
Natural period, T along X direction	0.98 s
Natural period, T along Y direction	1.46 s
Design acceleration coefficient, S_a/g along X direction	1.02
Design acceleration coefficient, S_a/g along Y direction	0.68

The wind load considerations were adopted according to [14].

Table 2. Wind load considerations according to [14]

Parameter	Value
Windward coefficient	0.8
Leeward coefficient	0.5
Basic wind speed	39 m/s
Risk coefficient	1
Terrain category	3
Topography factor	1
Importance factor	1

Property modifiers were adopted according to [8].

Table 3. Property modifiers

Element	Value
Slab	0.25 I_g
Beam	0.35 I_g
Column	0.7 I_g
Wall	0.7 I_g

IV.ANALYSIS

4.1. Dynamic Analysis

The structure was dynamically analysed using response spectrum method. [7] Damping ratio adopted was 0.05 [8] and percentage of imposed load considered was 25%. [7] The analysis results are represented in the following table.

Table 4. Dynamic analysis results

Parameter	Maximum Value	Load/Load Combination
Maximum Storey Displacement	119.9 mm	1.5 (Dead Load + Live Load)
Storey Shear	1787.18 kN	Dynamic earthquake load along X axis
Storey Overturning Moment	1513440 kNm	1.5 (Dead Load + Live Load)

4.2. Modal Analysis

Different modes of vibration were analysed. First two modes were represented as translation along X and Y directions and the third mode was represented as torsion. The fundamental natural period of torsional mode was obtained as 1.788 s which is less than 1.923 s. [8] The first three modes contributed more than 65% of mass distribution factor. [7] Number of modes that were used in the analysis of X and Y direction were 8 and 9 respectively. [7]

V.VALIDATION

The validation of the structure was done according to [8]. There is a checklist provided in Table 11 of [8] detailing certain specifications to be followed by the tall buildings. If those specified requirements are not met by the structure, it will need to go through SDR panel review process. The several specifications and the adherence of the structure to those specifications are given. Non-compliant parameters are brought into alignment with the specified code requirements. The various specifications in [8] and the compliance of the structure against those specifications are as follows.

1.1 : Building height is 62 m which is less than 250 m.

1.2 : The building is located more than 10 km away from any seismogenic fault.

1.5: The building house less than 20000 occupants

3.15 : The building does not have any transfer structure.

5.1.1: The building's structural system does not exceed the height restrictions specified in Table 1 of [8].

5.1.2: The building's slenderness ratio does not exceed the requirements specified in Table 2 of [8].

5.2: Plan aspect ratio of the structure = 2.22 < 5. Hence ok.

5.3: Lateral translational stiffness of any storey is not less than 70% of the lateral translational stiffness above.

5.4.1: The total drift at topmost usable floor = 119.9 mm. The maximum specified value = H/500 = 62000/500 = 124 mm. Hence ok.

5.5.1: The first and second natural modes of vibration are translations along X and Y respectively.

5.5.2: As we are designing under strength conditions, this clause is not applicable.

5.6.1: As we are not using precast floor slabs, this clause is not applicable.

5.6.2: The floor openings provided are in accordance with the specifications. The maximum area of opening is less than 30% of plan area of diaphragm.

5.7: The grade of concrete provided is M30 which conforms with the specification.

6.2: Wind tunnel studies are not required. Hence this clause is not applicable.

6.3: The building is located in seismic zone III. Hence this clause is not applicable.

7.2: The design is based on the cracked properties.

8.1: The structure is not having multiple towers connected with single podium. Hence this specification is not applicable.

8.4: The building is located in seismic zone III. Hence this clause is not applicable.

8.6: There are no flat slabs provided. Hence this clause is not applicable.

8.7: There are no framed tube or tube in tube or multiple tube systems provided. Hence this clause is not applicable.

9.4: The structure lies on hard rock. Hence it complies with this specification.

VI.STRUCTURAL DESIGN AND DETAILING

The structural design and detailing of various elements were done according to [9], [10] and [11].

VII.COMPARATIVE STUDY

A comparative analysis was done between the performance of tall buildings designed considering the specifications of [8] and those designed using conventional design practices without considering the specifications of [8]. In both the design practices [7], [9] and [10] are used for the analysis and design.

7.1 Design Considerations

7.1.1 Structural system

[8] encourages the use of robust structural systems like shear walls, coupled shear walls, and braced frames to enhance lateral load resistance. Conventional codes might allow for simpler systems, which may be less effective under dynamic loads.

7.1.2 Material properties

While both approaches utilize the material properties outlined in [10], [8] might suggest specific concrete mixes with enhanced ductility for improved performance in seismic zones.

7.1.3 Second order effects

[8] mandates the consideration of second order (P-Delta) effects, which account for the magnification of moments due to axial loads and lateral deflections. Conventional design might neglect these effects, potentially leading to underestimation of member forces.

7.1.4 Drift control

Stringent drift limitations are imposed by [8] to ensure occupant comfort and structural integrity under lateral loads. Conventional codes might have less stringent drift limits, leading to excessive lateral displacements.

7.1.5 Lateral loads

[8] places a significant emphasis on lateral loads like wind and earthquake. It specifies detailed procedures for dynamic analysis, considering the building's interaction with the wind and seismic ground motion. Conventional codes primarily focus on static analysis, potentially underestimating the true forces acting on the structure.

7.2 Comparative Performance

7.2.1 Safety

Buildings designed with [8] provisions will exhibit superior performance under lateral loads, resulting in enhanced life safety and reduced risk of collapse during earthquakes or strong winds.

7.2.2 Stiffness and Serviceability

The robust structural systems and drift control measures mandated by [8] will lead to a stiffer and more comfortable structure, minimizing lateral sway and improving occupant perception during wind or minor seismic events.

7.2.3 Material Consumption

Buildings designed with [8] might require a slightly higher quantity of high-performance concrete or additional reinforcement for shear walls and other lateral load resisting elements.

7.2.4 Construction Complexity

Implementing the specific requirements of [8], such as using coupled shear walls, might necessitate more complex construction techniques compared to conventional design.

7.3. Significance of IS 16700 (2023) [8]

7.3.1 Growing urbanization

With increasing population densities in cities, tall buildings are becoming more prevalent. [8] provides a robust framework for their design, mitigating the risks associated with lateral loads.

7.3.2 Improved serviceability

Stricter drift control measures mandated by [8] enhance occupant comfort by minimizing lateral sway during wind or minor earthquakes.

7.3.3 Seismic vulnerability

India is a seismically active region. [8] incorporates earthquake engineering principles, ensuring buildings can withstand seismic events with minimal damage.

7.3.4 Sustainable design

A well-designed tall building with proper lateral load resistance experiences less damage during earthquakes, leading to lower repair costs and potentially extending its lifespan.

While conventional design practices based on [7] and [9] might be sufficient for low-rise buildings, [8] offers a significant safety and performance advantage for tall buildings in India. Its emphasis on lateral load analysis, robust structural systems, and drift control ensures the safety and serviceability of these structures during wind and seismic events. The additional cost and construction complexity associated with adhering to [8] is a worthwhile investment for the enhanced safety and long-term benefits it provides.

VIII.CONCLUSIONS

Tall buildings offer an efficient solution for the intensifying demand for space, but in earthquake-prone areas like Kerala (Seismic Zone – III), the stability of such structures poses a challenge. Buildings over 50 m must adhere to [8], covering aspects like structural systems, geometric proportioning, wind, and earthquake resistance. Dynamic analysis was conducted, and designs were validated according to these standards.

This project focuses on the structural analysis and design of a tall building (G+19 Residential building) located in Seismic zone III with a plan area of 30 m x 13.5 m. It is a residential building of G+19 with floor-to-floor height of 3 m. The analysis of tall buildings and its design in accordance with [8] provides valuable insights into dynamic analysis methods and code provisions aimed at enhancing seismic resistance. The project includes the dynamic analysis of the building using response spectrum analysis, offering a comprehensive understanding of the structural behaviour under seismic forces and laying the foundation for a robust design approach.

Adherence to the specifications outlined in [8] is the cornerstone of the paper. The strict compliance with the code's guidelines ensures standardized practices for seismic-resistant structures, and this meticulous approach is essential, especially in seismic-prone zones, where the safety and stability of tall buildings are the paramount concerns. The comparative analysis between the design based on [8] and conventional design approach underlines the significance of [8] for enhanced seismic resistance of the building. The code's provisions, considering factors such as site-specific ground motion, building configuration, and material properties, also play a pivotal role in enhancing the overall seismic resilience of tall buildings.

In practical terms, the paper recommends the widespread implementation of [8] in the design and construction of tall buildings in seismic-prone zones. Engineers and architects are encouraged to embrace these provisions to enhance the resilience of structures, thereby contributing to the overall safety and sustainability of the built environment. By incorporating the seismic design principles outlined in [8], the engineering community will be able to make significant strides towards creating structures that not only meet safety standards but also withstand the challenges posed by seismic activities.

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