International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 12 | Dec 2025 www.irjet.net p-ISSN: 2395-0072

COMPARATIVE STUDY OF HORIZONTAL STRUCTURAL BEHAVIOR IN TALL BUILDINGS CONSTRUCTED USING VARIOUS CONCRETE GRADES

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Abstract - *Horizontal structural behavior (HSS) is one of the most significant issues related to earthquake design of tall buildings, especially those located in areas where earthquakes are common. The mechanical characteristics of materials, specifically concrete type/grade, have an effect on stiffness, mass, and dynamic responses of these types of structures. In this paper, the seismic performances of tall buildings made of various types of concrete (concrete grade of M25, M40 and precast concrete) have been compared through an analytical study. To compare the performance of three dimensional building models created based on Indian Standards, linear static analysis and response spectrum analysis have been used by using software called ETABS. Results have indicated that high strength concrete produces higher stiffness than low strength concrete which reduces the lateral displacement and improves the drift control but has higher base shear forces. As a result, the overall HSS of precast concrete is better than other two types of concrete. This study emphasizes the necessity of selecting appropriate strength of concrete for enhanced seismic safety, serviceability and economy of tall building structure.*

Key Words: Tall buildings, Concrete grade, Horizontal structural behaviour, Seismic analysis, Storey drift, Base shear, ETABS

1. INTRODUCTION

1.1 Rapid Growth of Tall Buildings and Challenges Due to Lateral Loads

Urban growth has increased the number of high rise buildings that are being constructed in urbanized areas. The lack of land availability has made it necessary for builders to build taller and closer together. Building codes, engineering technology, computer aided analysis tools, etc., have allowed for designers to create even taller and slenderer buildings than ever before. As buildings get taller, so does their susceptibility to horizontal loading such as earthquakes and winds. Horizontal loadings produce significant amounts of shear force, moment, and overturning at the base of a building which determine how safe the building is and how well it will perform under extreme conditions. Tall buildings are different from short buildings because of the way they respond dynamically to loads due to the higher mode numbers of vibrations, the increased amount of flexibility of the structure, and the interaction between the masses and stiffness's along the entire length of the building.

1.1.1 Role of Concrete Grade in Stiffness, Mass, and Seismic Performance

The quality of the concrete has a significant influence on how stiff, strong and massive a reinforced or precast structural member will be. The higher the quality of the concrete the higher the compressive strength and elastic modulus that it will have and therefore, the stiffer the columns, beams and walls will be. This increased stiffness results in lower lateral deflections and story drifts when subjected to wind and seismic loading, and therefore better overall structural performance. However, a higher quality of concrete may result in an increase in the mass of the structure and since seismic inertia forces are proportional to mass, then this can affect the seismic force generated by earthquakes (Neville, 2011).

From a seismic performance viewpoint, the quality of concrete also has an effect on cracking behavior, energy absorption and post-elastic response of structural members. High strength concrete has a superior load carrying capability, however, it may lose its ductility if the detailing does not allow sufficient deformation to occur. Therefore, a balance must be achieved between strength and ductility to achieve satisfactory seismic performance. In the case of precast concrete structures, high strengths of concrete are commonly used to counteract stresses developed during fabrication, transportation and construction, whilst also providing enhanced durability and serviceability of tall building structures (Nilson et al., 2010).

1.1.2 Need for Comparative Evaluation of Different Concrete Grades in Tall RCC and Precast Buildings

Most design approaches to tall building construction utilize uniform concrete grades throughout the structure, which is likely not the best combination from both an engineering and economic perspective. Tall structures have varying demand levels at various heights of the structure; lower floors experience larger axial forces and moment requirements, whereas upper floors are subjected to displacement and other dynamic load requirements. Therefore, the utilization of different concrete grades in strategically selected structural elements will improve structural efficiency, reduce materials needed, and better resist seismic events.

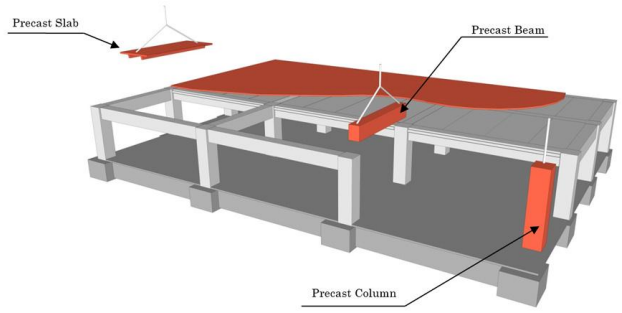


Figure-1: Precast Member

1.1.3 Objectives and Scope of the Present Study

The primary objective of the present study is to evaluate and compare the horizontal structural behavior of tall buildings constructed using different concrete grades under seismic and wind loading conditions. The study aims to quantify the influence of concrete grade on key response parameters such as base shear, story displacement, story drift, natural period, and internal force distribution. Analytical models representing conventional reinforced concrete and precast concrete construction are developed and analyzed using ETABS in accordance with Indian Standard codes.

The scope of the study is limited to linear dynamic analysis as per IS 1893 (Part 1):2016 and wind load analysis as per IS 875 (Part 3):2015. The findings are intended to support structural engineers in selecting appropriate concrete grades for tall buildings, ensuring safety, serviceability, and economic efficiency. The outcomes of this research also aim to contribute to the existing body of knowledge by providing a clear comparison of material-grade influence on lateral performance of tall RCC and precast buildings (Bureau of Indian Standards, 2016).

2. LITERATURE REVIEW

2.1 Overview of Literature Review

The literature review forms a critical foundation for understanding the existing research related to the horizontal structural behavior of tall reinforced concrete (RC) and precast concrete buildings. Previous studies have extensively examined the response of tall buildings under lateral loads such as earthquakes and wind; however, variations in material properties, especially concrete grades, have often been treated simplistically. This section systematically reviews earlier research focusing on lateral load response, the influence of concrete strength on seismic behavior, comparative analytical studies using ETABS software and Indian Standard codes, and identifies gaps that motivate the present research.

2.1.1 Lateral Load Response of Reinforced Concrete and Precast Buildings

Numerous studies have investigated the lateral load response of reinforced concrete buildings, highlighting the importance of stiffness distribution, structural configuration, and detailing in controlling seismic and wind-induced effects. Tall RC buildings are particularly sensitive to lateral forces due to increased flexibility and higher mode participation. Research has shown that inadequate lateral stiffness can result in excessive story drift and displacement, leading to structural and non-structural damage (Taranath, 2016).

2.1.2 Effect of Concrete Strength on Seismic Performance

Concrete strength significantly affects the seismic performance of buildings by influencing stiffness, strength, cracking behavior, and energy dissipation capacity. Studies have reported that higher-strength concrete increases lateral stiffness, resulting in reduced story displacements and drift demands. However, high-strength concrete may also exhibit more brittle behavior if not accompanied by adequate ductile detailing, particularly in seismic regions (Park & Paulay, 1975).

2.1.3 Comparative Studies Using ETABS and IS 1893

With the advancement of computational tools, ETABS has become one of the most widely used software packages for analyzing tall buildings subjected to lateral loads. Several studies have employed ETABS to evaluate seismic response parameters such as base shear, natural period, story drift, and mode shapes in compliance with IS 1893 provisions. These studies confirm that response spectrum analysis provides reliable estimates of seismic demands for regular tall buildings (CSI, 2018).

3. RESEARCH SIGNIFICANCE AND OBJECTIVES

3.1 Research Significance

Understanding the influence of material properties on the horizontal behavior of tall buildings has become increasingly important due to growing urban density and seismic risk in many regions. While structural systems and geometry have traditionally dominated design considerations, material-level parameters—particularly concrete grade—directly affect stiffness, mass, and dynamic response of tall structures. Variations in concrete strength alter lateral load resistance mechanisms, influencing seismic force distribution, deformation capacity, and vibration characteristics. Therefore, systematic investigation of horizontal behavior under varying concrete grades is essential for developing performance-efficient and resilient tall building designs (Booth et al., 2015).

3.1.1 Importance of Understanding Horizontal Behaviour with Varying Concrete Grades

The horizontal behavior of tall buildings is governed by complex interactions between structural stiffness, mass distribution, and energy dissipation capacity. Concrete grade significantly influences these parameters by modifying elastic modulus and compressive strength of structural elements. Higher-grade concrete generally increases stiffness, resulting in reduced lateral displacements and drift, but may also attract higher seismic forces due to increased mass participation. Conversely, lower-grade concrete offers greater deformability but may result in excessive lateral movements if not adequately designed (Fardis, 2009).

3.1.2 Practical Relevance for Structural Designers and Precast Construction

From a practical standpoint, the findings of this research hold direct relevance for structural designers engaged in both conventional RCC and precast construction. Designers frequently rely on uniform material grades for simplicity, which may not be optimal for tall buildings with varying force demands along the height. The use of higher-grade concrete in critical load-resisting components such as columns and shear walls, combined with normal-grade concrete in secondary elements, can enhance structural efficiency and reduce construction costs.

3.2 Research Objectives

The primary objective of this study is to analytically investigate and compare the horizontal structural behavior of tall buildings constructed using different concrete grades under seismic loading. The research focuses on quantifying the influence of material variation on critical seismic response parameters through code-compliant numerical modeling and analysis.

3.2.1 Evaluation of Base Shear Variation

One of the key objectives of the study is to evaluate the variation of base shear resulting from changes in concrete grade. Base shear represents the total seismic force transferred to the foundation and is influenced by structural mass, stiffness, and natural period. By analyzing base shear response for buildings with different concrete grades, the study aims to identify trends in force demand and assess how material stiffness influences seismic force attraction in tall buildings (Clough and Penzien, 2003).

3.2.2 Comparison of Storey Displacement and Drift

Another important objective is to compare story displacement and inter-story drift among building models with varying concrete grades. These parameters are critical indicators of structural performance and serviceability under lateral loads. Excessive drift can lead to damage in non-structural components and compromise occupant safety. The study seeks to evaluate how increased concrete stiffness contributes to drift control and compliance with code-specified limits (Ghosh, 2010).

3.2.3 Study of Changes in Natural Period and Structural Stiffness

The natural period of a building is a fundamental dynamic property that influences seismic demand and response spectrum values. Changes in concrete grade directly affect member stiffness and, consequently, the natural period of the structure. This research aims to study how variations in concrete strength modify the dynamic characteristics of tall buildings, particularly the fundamental period and modal behavior, which play a crucial role in seismic response evaluation (Chopra and Goel, 2011).

4. METHODOLOGY

4.1 Description of Building Models

The methodology adopted in this research involves numerical modeling and seismic analysis of tall building structures to evaluate the influence of varying concrete grades on horizontal structural behavior. Multiple three-dimensional building models are developed to represent conventional reinforced concrete and precast concrete construction. The models are idealized as moment-resisting frame systems, which are commonly used in tall building construction due to their flexibility and architectural adaptability. The structural configuration is kept consistent across all models to ensure that the observed variations in response are primarily attributed to changes in material properties rather than geometry or layout (Ali and Moon, 2007).

4.1.1 Geometry and Configuration of Tall Building Models

The geometric configuration of the building models is designed to represent a regular tall building plan, minimizing torsional irregularities and ensuring uniform mass and stiffness distribution. Regularity in plan and elevation is maintained in accordance with seismic design recommendations to obtain reliable analytical results. The building height, bay spacing, and member dimensions are selected to reflect realistic proportions used in contemporary tall buildings, ensuring practical relevance of the study (ASCE, 2017).

Table-1: Geometry of Models

Serial Number	Building 's Geometry	Value (mm)
01	Length of the Beam	3750 in X-Direction
02	Dimension of the Beam	450*650
03	Dimension of the Column	650*750
04	Height of the Ground Floor	3500
05	Height of the Each Floor	3000
06	Total Height of the Floor	63500
07	Thickness of the Slab	155
08	Plan Area of the Model (Centre to Centre)	22500*21000

4.1.2 Storey Height, Plan Dimensions, and Structural System

Uniform story heights are adopted throughout the building to simplify modeling and maintain vertical regularity. The plan dimensions are selected to provide adequate lateral resistance in both principal directions while avoiding excessive slenderness. The structural system consists of reinforced concrete beams, columns, and slabs forming a space frame system capable of resisting gravity and lateral loads. This configuration enables effective transfer of seismic forces from superstructure to foundation and allows meaningful comparison of dynamic characteristics across different concrete grades (Mac Gregor and Wight, 2012).

4.2 Material Properties

Material properties are a critical component of the analytical study, as concrete grade directly influences stiffness, strength, and mass of structural members. The models incorporate different concrete grades commonly used in Indian construction practice to examine their effect on seismic response parameters. All material properties are defined in accordance with relevant standards to ensure accuracy and consistency in analysis (Mehta and Montero, 2014).

4.2.1 Concrete Grades Used (M25, M40, and Precast Concrete)

Normal-strength concrete of grade M25 is used to represent conventional RCC construction, while higher-strength concrete of grade M40 is adopted for precast structural elements. Precast concrete is modeled with enhanced material properties reflecting controlled manufacturing conditions and improved durability. The elastic modulus, unit weight, and compressive strength values are assigned based on standard empirical relationships and code recommendations, allowing realistic representation of material behavior under lateral loads (Neville and Brooks, 2010).

4.2.2 Reinforcement Details

Reinforcement is modeled using high-strength steel commonly adopted in seismic design of RC structures. The reinforcement properties are defined to ensure adequate strength and ductility in beams and columns. Although reinforcement detailing is not explicitly modeled at the element level, the assigned properties reflect ductile detailing provisions recommended for seismic resistance. This approach ensures that global response characteristics such as displacement and base shear are realistically captured (Paulay, 1996).

4.3 Software Used

ETABS is employed for modeling, analysis, and evaluation of seismic response of the building models. ETABS is a specialized structural analysis software developed for building systems and is widely recognized for its accuracy in simulating dynamic behavior of tall buildings. The software supports linear static, response spectrum, and modal analysis, enabling comprehensive assessment of horizontal structural behavior. Its ability to define different material properties and load combinations makes it particularly suitable for comparative studies involving multiple concrete grades (CSI, 2020).

4.4 Load Considerations

All relevant gravity and lateral loads are considered in accordance with Indian Standard codes to simulate realistic loading conditions. Load magnitudes are applied consistently across all models to maintain comparability of results. The load definitions reflect typical residential or commercial building usage and comply with codal recommendations for structural safety (IS 875).

4.4.1 Dead Load, Live Load, and Floor Finish Load

Dead loads include the self-weight of structural members and permanent fixtures, automatically calculated by the software based on assigned material densities. Live loads represent occupancy-related loads and are applied uniformly on floor slabs. Additional floor finish loads are included to account for non-structural components such as flooring and finishes. These loads contribute to the seismic weight of the structure and influence lateral force calculations (Arumugam, 2013).

4.4.2 Seismic Load as per IS 1893:2016

Seismic loads are applied using response spectrum analysis in accordance with IS 1893 (Part 1):2016. The design spectrum is generated based on seismic zone, soil type, importance factor, and response reduction factor. Modal analysis is carried out to capture dynamic characteristics of the structure, and modal responses are combined using appropriate combination rules. This approach provides a

rational estimation of seismic demands on tall buildings (Murty, 2019).

4.5 Seismic Parameters

Seismic parameters are selected in accordance with Indian seismic zoning and design recommendations. These parameters directly influence the magnitude of seismic forces and the dynamic response of the structure. Uniform seismic parameters are adopted across all models to isolate the effect of concrete grade variation (Bommer and Pinho, 2006).

4.5.1 Seismic Zone, Importance Factor, and Response Reduction Factor

The seismic zone factor represents the expected intensity of ground motion at the site. The importance factor accounts for the functional significance of the building, while the response reduction factor reflects the energy dissipation capacity of the structural system. These parameters collectively determine design seismic forces and are selected to represent realistic seismic design scenarios for tall buildings (Bozorgnia and Bertero, 2004).

4.5.2 Soil Type and Damping Considerations

Soil conditions significantly affect seismic response due to soil–structure interaction effects. Medium soil conditions are considered in this study, as they are commonly encountered in urban regions. A standard damping ratio is adopted to represent inherent energy dissipation in reinforced concrete structures. These assumptions are consistent with seismic analysis practices for linear dynamic analysis (Wolf and Deeks, 2004).

4.6 Analysis Procedure

The analysis procedure follows a systematic approach beginning with model development, load application, and dynamic analysis. Linear elastic behavior is assumed for all structural members, which is acceptable for preliminary comparative evaluation of seismic response. The results obtained provide insight into relative performance trends among different concrete grades (Wilson, 2002).

4.6.1 Linear Static and Response Spectrum Analysis

Linear static analysis is used to evaluate gravity load effects, while response spectrum analysis is conducted to capture dynamic seismic response. Modal participation factors and mass participation ratios are examined to ensure sufficient modes are considered. This combined approach enables accurate estimation of base shear, displacement, and modal properties of tall buildings (Chopra, 2012).

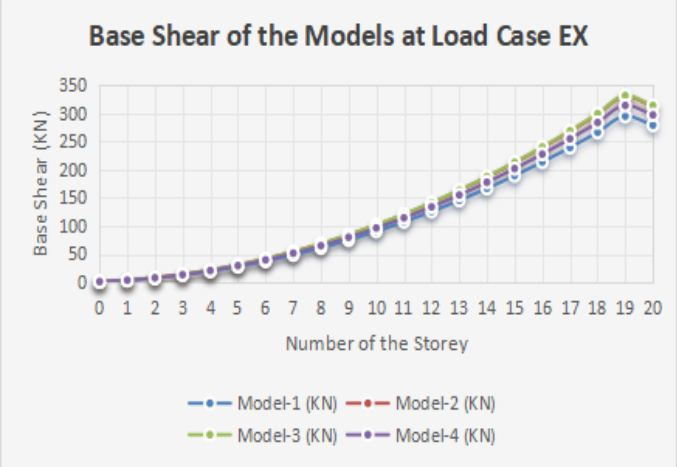
4.6.2 Load Combinations as per IS Codes

Load combinations are applied in accordance with IS 1893 and IS 456 provisions to account for simultaneous action of gravity and lateral loads. Both strength-based and serviceability-based combinations are considered to evaluate critical response parameters. This ensures that the analysis results comply with codal safety requirements and reflect realistic design conditions (Subramanian, 2014).

5. RESULTS AND DISCUSSION

5.1 Base Shear Comparison

Base shear is a fundamental seismic response parameter representing the total horizontal force transferred from the superstructure to the foundation during an earthquake. It is directly influenced by the seismic weight, stiffness, and dynamic characteristics of the structure. In this study, base shear values are extracted from response spectrum analysis results for building models constructed using different concrete grades. The comparison reveals that buildings with higher concrete grades exhibit relatively higher base shear due to increased stiffness and mass participation, which results in greater seismic force attraction under identical ground motion conditions (Humar, 2012).



Fogure-2: Base Shear of Models.

5.2 Story Displacement

Story displacement is a critical response parameter that reflects the lateral flexibility of a building under seismic and wind loads. Excessive displacement can cause serviceability issues, non-structural damage, and discomfort to occupants. In tall buildings, displacement demand typically increases with height due to cumulative deformation effects. The results obtained from the analysis show a systematic reduction in maximum story displacement with increasing concrete grade, attributed to enhanced stiffness of structural members (Ellingwood, 2001).

5.2.1 Maximum Storey Displacement under Lateral Loads

The maximum story displacement is observed at the topmost levels of the building, consistent with cantilever-type behavior of tall structures under lateral loads. Buildings constructed with M25 concrete exhibit higher displacement values compared to those using M40 and precast concrete. The reduction in displacement with higher concrete grades confirms the role of material stiffness in controlling lateral deformation. This behavior is particularly significant for tall buildings, where displacement often governs design rather than strength considerations (Stafford Smith and Coull, 1991).

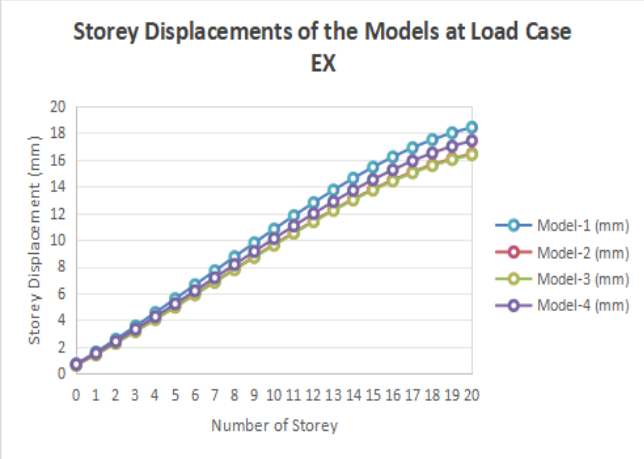


Figure-3: Story Displacement.

5.3 Storey Drift

Storey drift, defined as the relative displacement between consecutive floors, is a key indicator of potential damage to structural and non-structural components. Excessive drift may lead to cracking of partitions, façade damage, and failure of structural elements. The drift profiles obtained from the analysis provide valuable insight into deformation distribution along the height of the building (Bertero and Bertero, 2002).

5.4 Natural Period

The natural period of a building represents its fundamental dynamic characteristic and significantly influences seismic demand. It is primarily governed by structural mass and stiffness. Changes in concrete grade alter stiffness properties of members, leading to variation in the fundamental time period. Accurate estimation of the natural period is essential for reliable seismic response evaluation (Priestley, 2003).

6. CONCLUSION

This study presented a comparative evaluation of the horizontal structural behavior of tall buildings constructed using different concrete grades under seismic loading. Analytical results clearly demonstrate that concrete grade significantly influences key seismic response parameters, including base shear, storey displacement, inter-storey drift, and natural period. Buildings constructed with higher-grade concrete exhibited increased stiffness, resulting in reduced lateral displacements and improved drift control across the height. Although higher stiffness led to marginally higher base shear demand, the overall seismic performance improved due to enhanced deformation control and structural stability. Precast concrete models showed superior horizontal performance owing to better material quality and stiffness characteristics. The reduction in natural period observed in higher-grade concrete buildings confirms their increased resistance to lateral deformation. Overall, the findings emphasize that material selection should be treated as a critical design parameter in tall buildings rather than a secondary consideration. The study supports the adoption of optimized concrete grades to achieve improved seismic resilience, serviceability, and safety in tall reinforced concrete and precast building systems.

7. LIMITATIONS OF THE STUDY

Study limited to linear analysis, regular geometry, and specific seismic assumptions only.

8. FUTURE SCOPE OF WORK

Future research can extend the present study by incorporating nonlinear static and nonlinear time-history analyses to capture inelastic behavior under strong ground motions. The influence of mixed concrete grades within the same building, such as higher grades in lower storeys and normal grades in upper storeys, can be investigated for structural and economic optimization. Further studies may include irregular building configurations, different structural systems such as shear walls, outrigger systems, and diagrids, and varying soil conditions considering soil–structure interaction effects. Experimental validation using scaled models or field data from existing tall buildings would enhance the reliability of analytical results. Additionally, performance-based seismic design approaches can be explored to develop design guidelines for optimized use of concrete grades in tall reinforced concrete and precast buildings.

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