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

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Abstract - *Concrete's high strength-to-weight ratio makes it a popular choice among builders of tall buildings due to its ability to resist heavy loads while providing ample vertical space. Tall building construction has increased exponentially over recent years and the resulting increased demand for understanding the horizontal structural response of these structures when subjected to wind or seismic forces necessitates an enhanced understanding of how the horizontal structural performance of tall buildings can be influenced by the properties of concrete used to build them. A number of factors that affect the overall lateral performance of tall structures include ductility, strength, stiffness, and strength-to-weight ratios; however, the most significant factor is likely the type of concrete selected (concrete grade). A review of the literature was conducted to evaluate the comparative effects of four types of concrete used in the construction of tall buildings (normal-strength concrete (NSC), high-strength concrete (HSC), high-performance concrete (HPC) and ultra-high performance concrete (UHPC)) on both the horizontal structural performance characteristics of tall buildings and the lateral performance characteristics of tall buildings. In addition to reviewing previous studies involving both analytical and numerical approaches, this review included a review of previous experimental studies related to the use of different types of concrete in the construction of tall buildings.*

Key Words: Tall buildings; Concrete grade; Lateral structural behavior; Seismic performance; Wind response; Performance-based design.

1. INTRODUCTION

1.1 Background on the Rapid Growth of Tall Buildings

The rapid rate of urban development has increased the need for effective use of available land in large cities due to growing populations. The limited land and increasing costs of that land are making it necessary for urban planners and developers to incorporate vertical development into their plans. This has resulted in an increase in the number of tall building projects in dense, metropolitan areas; the ability to develop these types of projects is also being made possible by advances in construction technology, materials science and computer-aided engineering. Tall buildings are becoming a critical component of developing residential, commercial and mixed-use projects in contemporary urban settings.

1.2 Importance of Horizontal (Lateral) Structural Behavior in Tall Structures

Due to the height and flexibility of tall structures, they are very sensitive to large horizontal or lateral displacements (caused by wind and earthquake forces) that can cause inter-story drifts, dynamic vibrations, and potentially structural failure; therefore, excessive lateral movement in tall structures can create serviceability problems with the building, cause structural damage and be uncomfortable to people occupying the building. The safety and stability of tall structures can also be compromised by lack of sufficient lateral resistance if an extreme load event occurs (e.g., earthquake or hurricane). Thus, assessing and controlling horizontal structural behavior in tall buildings is a significant part of designing and assessing the performance of tall buildings.

1.3 Role of Concrete Grade in Influencing Structural Performance

Concrete grade is one of the most influential parameters affecting the structural performance of tall buildings. It directly governs the mechanical properties of structural members and significantly impacts the overall response of the building under lateral loading conditions.

1.3.1 Influence on Stiffness and Strength

Structural members made with higher strength grade concretes exhibit higher modulus of elasticity and compressive strengths; both are responsible for providing a stiffer structure that will carry larger loads and therefore provide less lateral displacement in the event of seismic or wind loading events. Stiffer structures also provide less inter-story drift as compared to softer structures. Higher strength concretes allow engineers to design structural members smaller than would be required if using lower strength concretes (assuming the same strength requirements), resulting in structurally more efficient designs.

1.3.2 Influence on Ductility and Energy Dissipation

The ability to deform (ductility) is an important factor in how well a tall building will perform when subjected to earthquakes. High-strength concrete provides increased strength, however; high-strength concrete has less deformation capability than normal-strength concrete. This lower deformation potential affects its ability to dissipate energy during earthquake-induced motions, develop cracks as it deforms, and form plastic hinges (the locations where the structure begins to yield), which are all critical aspects that affect the overall structural response to lateral loads. Therefore, selecting a suitable concrete grade for a tall building requires a combination of sufficient strength and adequate ductility to prevent brittle failures and encourage controlled inelastic responses during seismic activities.

1.3.3 Influence on Overall Lateral Performance

Tall building's total lateral behavior is determined by the three properties of stiffness, strength and ductility. The global structural response of a tall building is affected by its concrete grade including natural time period, base shear demand, mode shape and dynamic magnification factor. Differences in the concrete grade will have a significant impact on how the lateral loads are distributed and deformed throughout the structure which has an influence on both serviceability and safety performance.

1.4 Need for Comparative Assessment of Different Concrete Grades

While many studies have studied the behavior of tall buildings, most studies have focused on a single (concrete) strength or structural configuration. The current body of knowledge does not include an extensive comparative study of the behavior of various concrete strengths with the same geometrical characteristics and loadings. This comparative study is needed to compare and contrast the advantages and disadvantages of each of the concrete grades in relation to their lateral response, material use efficiency and seismic behavior. It can also provide useful guidelines for designers and researchers for selecting suitable concrete grades for tall building construction.

2. LITERATURE REVIEW ON HORIZONTAL STRUCTURAL BEHAVIOR OF TALL BUILDINGS

This section presents a comprehensive review of previous studies focusing on the horizontal structural behavior of tall buildings, with particular emphasis on the influence of different concrete grades. The reviewed literature includes analytical, numerical, and experimental investigations addressing wind- and seismic-induced responses, serviceability requirements, and strength-based performance criteria.

2.1 Studies on Lateral Load Behavior of Tall Buildings

2.1.1 Wind-Induced Response of Tall Structures

Many research studies have illustrated that wind forces are typically the most important load cases for design of high-rise structures, particularly when they are built in areas where the seismic activity is moderate. The many ways in which wind affects tall structures (longitudinal and transverse motion, torsion) all contribute to both the amount of the lateral displacement and how much the acceleration will be. Increased structural flexibility due to building height and slenderness also increase wind response, so it is a primary design factor. Numerical simulation models and wind tunnel testing have shown that the properties of lateral stiffness and damping can have a significant impact on reducing the vibrational responses to wind induced loads and maintaining comfort for occupants.

2.1.2 Seismic Response Characteristics

Tall buildings have undergone extensive research of their Seismic Response via Time-History Analysis, Experimental Methods and Response Spectrum Analysis. Literature has indicated that Seismic Forces cause tall structures to exhibit complex Dynamic Behavior which includes Higher Mode Effects. Inter-Story Drift and Plastic Hinge Formation are two Critical Parameters used for evaluation of the Seismic Performance of Tall Structures. The Distribution of Mass and Stiffness throughout the Height of the Building is a significant factor in determining the Seismic Demand of Tall Buildings, while Material Properties (i.e., Concrete Grade) are important in Controlling Damage Patterns During Earthquakes.

2.2 Literature on Tall Buildings Using Normal Strength Concrete (NSC)

2.2.1 Lateral Displacement and Drift Characteristics

Due to its ease of manufacturing and cost efficiency, Normal Strength Concrete (NSC), has historically been used for the construction of tall buildings. However, research demonstrates that tall buildings built using NSC exhibit larger lateral displacement and inter-story drift than shorter structures due to its relatively lower stiffness. As building height increase, controlling drift is identified as a significant problem in tall structures when NSC is utilized; therefore, increased member size or additional lateral load resisting systems are commonly required.

2.2.2 Base Shear and Stiffness Behavior

The research data indicates that tall buildings utilizing NSC exhibit significantly less base shear as a result of the added flexibility and extended natural period. Although this may seem beneficial when viewed through the lens of force

demand, the loss of stiffness can cause problems with the ability of the structure to function properly. Research studies have shown that excessive flexibility in structures built with NSC for tall buildings may negatively affect the performance of these structures during extreme wind or earthquake conditions.

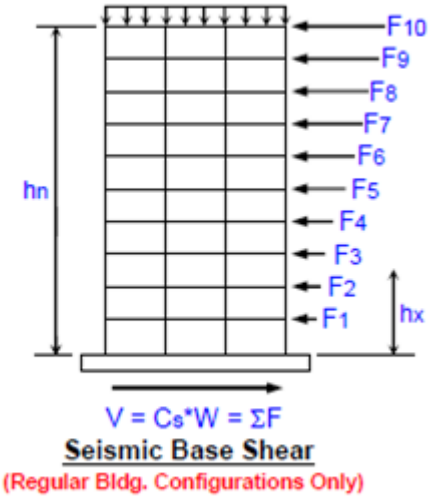

Figure-1: Base Shear

2.3 Literature on Tall Buildings Using High Strength Concrete (HSC)

2.3.1 Improvements in Stiffness and Reduction in Member Sizes

Researchers have found that High-Strength Concrete (HSC), with superior compressive strength and stiffness, is a popular subject of study for tall buildings due to the benefits of using high-strength concrete in the form of increased usable floor space due to smaller column and wall sizes, lower total building weight, and an improvement in controlling lateral displacement and drift due to higher stiffness.

2.3.2 Impact on Dynamic Characteristics

Research has shown that high-strength concrete (HSC) structures will experience a reduced period of vibration (natural time period) as opposed to non-reinforced steel-concrete composite (NSC) structures. The increased stiffness of HSC structures results in a different dynamic response than would be experienced by an NSC structure subjected to seismic loads and therefore may result in larger base shear forces. Therefore researchers recommend that when designing for seismic activity and utilizing HSC, great care should be taken to perform adequate dynamic analysis.

2.4 Literature on Tall Buildings Using High Performance Concrete (HPC)

2.4.1 Enhanced Durability and Mechanical Performance

High Performance Concrete (HPC) has gained attention due to its improved mechanical properties and superior durability characteristics. Research indicates that HPC offers enhanced resistance to cracking, creep, and shrinkage, which is particularly beneficial for tall buildings subjected to long-term lateral loading effects. These properties contribute to sustained stiffness and long-term structural performance.

2.4.2 Lateral Load Response under Extreme Conditions

Studies investigating the lateral behavior of HPC-based tall buildings report improved performance under extreme wind and seismic conditions. Reduced lateral displacements and enhanced post-cracking behavior have been observed, making HPC suitable for high-rise structures in aggressive environments or high-load regions.

2.5 Literature on Ultra-High Performance Concrete (UHPC) in Tall Buildings

2.5.1 Emerging Research and Pilot Applications

UHPC represents an emerging class of cementitious materials characterized by extremely high strength and enhanced tensile properties. Literature on UHPC in tall buildings is relatively limited and primarily consists of experimental studies and pilot projects. Researchers have explored its potential use in critical structural components such as coupling beams, outriggers, and core elements.

2.5.2 Lateral Behavior and Energy Dissipation

Experimental studies suggest that UHPC exhibits superior energy dissipation capacity due to fiber reinforcement and improved tensile behavior. Its high stiffness and strength significantly enhance lateral resistance, although its influence on global building response requires further investigation.

3. STRUCTURAL SYSTEMS IN TALL BUILDINGS AND INTERACTION WITH CONCRETE GRADE

Structural systems play a critical role in controlling the horizontal behavior of tall buildings. The effectiveness of these systems is strongly influenced by the grade of concrete used, as material properties directly affect stiffness, strength, ductility, and overall structural efficiency under lateral loads.

3.1 Moment-Resisting Frame Systems

Moment-resisting frame systems consist of beams and columns rigidly connected to resist lateral loads primarily through flexural action. These systems rely heavily on the

bending stiffness of frame members to control lateral displacement and drift.

3.1.1 Lateral Load Resistance Mechanism

In moment-resisting frames, lateral loads are resisted by the development of bending moments at beam–column joints. The stiffness of the frame is therefore dependent on the flexural rigidity of beams and columns, which is directly influenced by the concrete grade. Higher concrete grades enhance member stiffness, improving lateral load resistance.

3.1.2 Interaction with Concrete Grade

Studies indicate that the use of higher-grade concrete in moment-resisting frames leads to reduced lateral displacements and improved strength capacity. However, increased stiffness may also result in higher base shear demands under seismic loading. Additionally, ensuring adequate ductility through proper detailing becomes more critical when higher concrete grades are used.

3.2 Shear Wall and Core Wall Systems

Shear wall and core wall systems are widely adopted in tall buildings to provide substantial lateral stiffness and strength. These vertical structural elements resist lateral loads primarily through shear and flexural action.

3.2.1 Structural Role in Tall Buildings

Shear walls and core walls significantly enhance the lateral load-resisting capacity of tall buildings by limiting drift and improving overall stability. Central core walls are particularly effective in resisting torsional effects induced by asymmetric loading conditions.

3.3 Outrigger and Belt Truss Systems

Outrigger and belt truss systems are commonly used in high-rise and super-tall buildings to enhance lateral stiffness by coupling the core with perimeter columns.

3.3.1 Mechanism of Lateral Load Control

Outrigger systems transfer overturning moments from the central core to exterior columns, effectively reducing lateral deflections and base moments. Belt trusses distribute these forces uniformly among perimeter columns, improving overall structural efficiency.

4. COMPARATIVE EVALUATION OF HORIZONTAL STRUCTURAL BEHAVIOR

This section presents a comparative evaluation of the horizontal structural behavior of tall buildings constructed using different concrete grades. The assessment is based on key response parameters reported in the literature, including lateral displacement, inter-story drift, base shear, stiffness distribution, and dynamic characteristics under wind and seismic loading.

4.1 Effect of Concrete Grade on Lateral Displacement and Drift

Lateral displacement and inter-story drift are primary serviceability indicators for tall buildings and are highly influenced by material stiffness.

4.1.1 Lateral Displacement Characteristics

Studies consistently indicate that higher concrete grades result in reduced overall lateral displacement due to increased modulus of elasticity and enhanced member stiffness. Tall buildings constructed with high-strength and high-performance concrete demonstrate significantly lower roof displacements compared to those using normal-strength concrete, particularly under wind loading conditions.

4.1.2 Inter-Story Drift Control

Inter-story drift is a critical parameter governing damage potential during seismic events. Literature shows that higher concrete grades contribute to improved drift control by increasing lateral stiffness; however, excessive stiffness concentration may lead to localized damage if not properly distributed. Thus, the effectiveness of drift reduction depends not only on concrete grade but also on structural configuration and detailing.

4.2 Effect on Base Shear and Stiffness Distribution

The grade of concrete directly affects global stiffness, which in turn influences seismic force demand.

4.2.1 Base Shear Demand

Comparative studies reveal that buildings with higher concrete grades generally attract higher base shear under seismic loading due to reduced natural time periods. While increased base shear reflects enhanced stiffness, it also necessitates careful design to ensure adequate strength and ductility.

5. SEISMIC PERFORMANCE AND DUCTILITY CONSIDERATIONS

Seismic performance of tall buildings is governed not only by strength and stiffness but also by the ability of structural systems to undergo inelastic deformation without significant loss of load-carrying capacity. Concrete grade plays a critical role in defining ductility, energy dissipation, and damage characteristics under earthquake loading.

5.1 Ductility Demand and Capacity Across Concrete Grades

Ductility demand refers to the deformation required during seismic events, while ductility capacity represents the ability of the structure to accommodate such deformations without failure.

5.1.1 Ductility Demand in Tall Buildings

Tall buildings experience higher ductility demand due to increased flexibility, higher mode effects, and redistribution of seismic forces along the height. Literature indicates that ductility demand increases with building height and irregularity, making material selection a crucial design decision in seismic regions.

5.1.2 Ductility Capacity of Different Concrete Grades

Normal-strength concrete generally exhibits higher strain capacity and better post-cracking behavior, providing superior inherent ductility. In contrast, high-strength concrete tends to be more brittle, with reduced ultimate strain capacity. High-performance concrete, when combined with appropriate confinement and reinforcement detailing, can achieve a favorable balance between strength and ductility. Ultra-high performance concrete, particularly fiber-reinforced variants, demonstrates enhanced tensile strength and deformation capacity; however, its global ductility behavior in tall buildings requires further validation.

5.2 Energy Dissipation Mechanisms

Energy dissipation is a key parameter influencing seismic resilience, as it determines the extent to which earthquake-induced energy can be absorbed without severe structural damage.

5.2.1 Inelastic Deformation and Hysteretic Behavior

In conventional reinforced concrete structures, energy dissipation primarily occurs through yielding of reinforcement and controlled cracking of concrete. Studies show that normal-strength and high-performance concrete structures exhibit stable hysteretic behavior when properly detailed, whereas high-strength concrete structures may require enhanced confinement to prevent rapid strength degradation.

Table 1: Seismic Performance Characteristics Across Concrete Grades

Concrete Grade	Ductility Capacity	Energy Dissipation
NSC	High	Moderate–High
HSC	Moderate	Moderate
HPC	High	High

6. SUSTAINABILITY AND ECONOMIC CONSIDERATIONS

Sustainability and economic feasibility have become integral aspects of tall building design due to increasing environmental concerns and rising construction costs. The selection of concrete grade significantly influences material consumption, construction practices, life-cycle performance, and overall environmental impact. This section reviews existing literature addressing sustainability- and cost-related implications associated with the use of various concrete grades in tall buildings.

6.1 Material Efficiency and Reduction in Member Size

Material efficiency refers to the ability of a structural system to achieve required performance with minimum material usage.

6.1.1 Effect of Concrete Grade on Member Dimensions

Higher concrete grades enable increased load-carrying capacity, allowing for reduced cross-sectional dimensions of columns, walls, and core elements. Literature indicates that high-strength and high-performance concrete significantly reduce member sizes in tall buildings, leading to improved architectural flexibility and increased usable floor area. Reduced member size also contributes to lower overall building self-weight, which in turn reduces foundation demand and seismic force effects.

6.1.2 Structural Efficiency and Resource Optimization

Several studies highlight that the strategic use of higher concrete grades in critical structural components enhances overall material efficiency. Rather than uniformly increasing concrete strength throughout the structure, optimized grade distribution—such as higher grades at lower stories and core elements—results in efficient resource utilization while maintaining adequate lateral performance.

6.2 Construction Feasibility and Cost Implications

While higher concrete grades offer structural advantages, their practical implementation involves several construction-related considerations.

6.2.1 Construction Challenges and Practical Limitations

High-strength and high-performance concrete often require controlled mix designs, specialized quality control measures, and skilled workmanship. Literature reports challenges related to workability, curing requirements, and increased sensitivity to construction errors. UHPC, in particular, demands advanced mixing techniques and placement procedures, limiting its widespread application in conventional tall building projects.

6.2.2 Initial Cost versus Structural Benefits

Higher concrete grades generally incur higher material and production costs. However, studies indicate that these costs may be offset by reductions in member size, reinforcement quantity, and construction time. Economic evaluations suggest that although initial costs are higher, the overall project cost may remain competitive due to savings in formwork, foundation size, and usable floor area.

7. CONCLUSION

The current study has reviewed all of the available literature to compare the horizontal structural behavior of tall buildings constructed using various concrete strengths. From the results of the reviewed literature (analytical/numerical/experimental), it appears that the strength of the concrete used has a significant effect on the interstory drift, lateral deflection, stiffness distribution, dynamic response, and seismic performance of tall buildings. High-strength/high-performance concretes exhibit improved lateral stiffness and serviceability when subjected to wind loads and also have the potential to reduce the amount of material needed for each element. However, the use of higher strength concretes can result in an increase in the seismic forces required to resist earthquake induced deformations and a reduction in the inherent ductility of the structure unless proper details are included in the structure to provide adequate confinement. This review highlights that the best performance of the structural system is achieved when a performance based selection of the concrete strength is made along with the most suitable structural system and seismic design strategy. Ultra high performance concretes, which are one of the emerging materials, have shown great promise to improve the lateral resistance and durability of structures; however, there are very few applications of this type of concrete in tall building construction. Overall, the information provided in this review will be beneficial to researchers and practicing engineers to better understand the horizontal structural performance of tall building construction with various concrete strengths.

7.1. Limitations of the Review

While the review is all-encompassing regarding the topic area, it is also important to acknowledge the limitations of the review, specifically the reliance upon published literature, which will have a variety of model assumptions, structural configurations, loading conditions, and performance evaluation criteria; thereby making comparisons between these difficult. Many of the studies reviewed used numerical methods (i.e., simulation) and there was limited access to actual full scale experimental and/or building performance data for High-Performance Concrete (HPC), Ultra-High Performance Concrete (UHPC), etc. In addition, while many of the studies reviewed did address the construction practices, workmanship quality, etc. that affect the lateral response of the structure, they did not do so uniformly. The economic and sustainability assessment of the various systems were generally qualitative because consistent LCC (Life-Cycle Cost) and EI (Environmental Impact) information is not readily available. There is also potential to generalize results from some of the studies reviewed due to the use of different design codes and seismic characteristics by region. Therefore, there is an obvious need to develop standardized comparative frameworks, conduct large-scale experimental testing, and perform integrated LCC/EI analyses in future studies.

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