INVESTIGATING LATERAL RESPONSE VARIATIONS IN REINFORCED CONCRETE FRAMES WITH DIFFERENT TYPE OF CONCRETE: A REVIEW

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Abstract - *This review paper investigates the lateral response variations in reinforced concrete (RC) frame structures constructed using different types of concrete. Structural performance under lateral loads, such as those induced by seismic activity, is critical for ensuring the stability and safety of RC frames. The study explores how variations in concrete types,encompassing standard, high-strength, and lightweight concrete,impact parameters such as stiffness, ductility, energy dissipation, and overall resilience. Through a comprehensive analysis of recent experimental and computational studies, key trends and insights are synthesized, highlighting the role of concrete type in modulating the lateral load-bearing capacity and deformation characteristics of RC frames. Findings from this review underscore the potential for optimizing concrete selection to improve lateral response, thereby contributing to design recommendations for enhancing earthquake resilience. This review serves as a resource for civil engineers and researchers aiming to refine structural designs for improved safety and performance in diverse environmental conditions.*

Key Words: Lateral response, Reinforced concrete frames, Concrete types, Seismic performance, Structural resilience, Structural design optimization.

1.BACKGROUND

The investigation of lateral response in reinforced concrete (RC) frames has been a crucial area of structural engineering research for decades, primarily due to the high vulnerability of RC structures to lateral forces induced by seismic activities, wind loads, and other dynamic forces.

Early research efforts in the mid-20th century focused on understanding the fundamental behavior of RC structures under lateral loads, but at that time, concrete was generally treated as a homogeneous material with limited variation in concrete types or strengths. With advancements in material science during the 1980s and 1990s, the development of high-strength concrete (HSC) and ultra-high-performance concrete (UHPC) broadened the scope for investigating RC frames' lateral response. Researchers began conducting comparative studies between conventional concrete and these new types, focusing on their distinct material properties. HSC, for example, offered substantial improvements in terms of compressive strength but required careful design adjustments in reinforcement to prevent brittle failure modes under seismic loading.

During this period, the adoption of advanced concrete types, such as fiber-reinforced concrete, marked a significant milestone in construction technology. This innovative material offered substantial improvements in tensile strength, effectively reducing the risk of cracking under load.

Its unique composition, incorporating fibers into the concrete matrix, enhanced its ductility and energy absorption capacity. Structural tests highlighted its superior lateral performance, making it an ideal choice for buildings and infrastructure in regions prone to high seismic activity, where durability and resilience are critical.

2.RC FRAMES FOR STRUCTURAL STABILITY

Reinforced Concrete (RC) frames are essential for structural stability in modern construction, as they combine concrete's compressive strength with steel's tensile strength to create a highly resilient and load-bearing system. These frames form a rigid skeleton by connecting beams and columns, which helps distribute forces evenly throughout a structure, resisting external forces like wind and seismic activity.

RC frames are also valued for their ductility, allowing structures to withstand deformation without sudden collapse, particularly during earthquakes. They offer design flexibility, cost-effectiveness, and long-term durability, making them ideal for buildings of all types and sizes, from residential complexes to high-rise skyscrapers. Through effective soil-structure interaction, RC frames enhance the stability and safety of the structures they support, ensuring a solid foundation even in challenging environmental conditions.

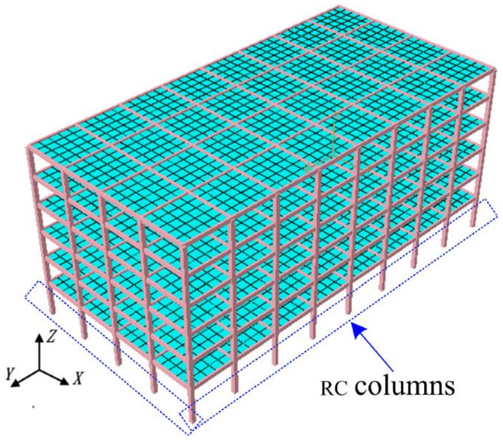

Figure-1: RC Frame Structure

2.1.Importance of lateral response in RC frames for structural stability

The lateral response of Reinforced Concrete (RC) frames is crucial for structural stability, as it determines the frame's ability to resist horizontal forces like wind and earthquakes. By effectively managing lateral loads, RC frames prevent excessive sway or displacement, which can lead to structural damage or collapse. This response enhances the frame's rigidity, allowing it to maintain balance and integrity under stress, thus safeguarding the building and its occupants in dynamic environmental conditions.

2.2.Purpose of investigating lateral variations with different concrete types

Investigating lateral variations with different concrete types in RC frames is essential to understand how each concrete mix affects the frame's ability to resist horizontal forces like wind and seismic loads. Different concrete grades have unique strengths, stiffness, and deformation characteristics, impacting the overall lateral stability and flexibility of the structure. By analyzing these variations, engineers can identify the optimal concrete type that provides the best balance of strength and ductility for a given structure. This research ensures that the RC frame can achieve maximum stability and safety while optimizing material costs and performance under varying lateral forces.

3.TYPES OF CONCRETE IN RC FRAMES

In reinforced concrete (RC) frames, different types of concrete are used depending on structural requirements, performance characteristics, and specific project needs. Here's an overview of the main types of concrete commonly used in RC structures:

3.1.Normal-Strength Concrete (NSC)

Normal-Strength Concrete (NSC) is a commonly used construction material characterized by a compressive strength typically ranging from 20 to 40 MPa (2900 to 5800 psi). Composed of standard aggregates, cement, water, and sometimes admixtures, NSC is known for its cost-effectiveness and suitability for a variety of applications, including residential and light commercial buildings. While it provides adequate structural performance for many typical loads, NSC has limitations in terms of durability and resistance to extreme conditions, making it less suitable for high-stress environments or structures requiring enhanced performance.

3.2.High-Strength Concrete (HSC)

High-Strength Concrete (HSC) is engineered to achieve compressive strengths exceeding 40 MPa (5800 psi), often reaching up to 100 MPa (14,500 psi) or more. This type of concrete is formulated using specialized cements, reduced water-to-cement ratios, and carefully selected aggregates, which contribute to its superior performance characteristics. HSC offers enhanced load-bearing capacity, allowing for more slender and efficient structural designs, making it ideal for high-rise buildings, bridges, and other applications subjected to significant loads. Additionally, HSC exhibits improved durability and resistance to environmental factors, which helps extend the lifespan of structures in challenging conditions. However, its higher material costs and specific mixing requirements can be considerations in its use.

3.3.Self-Consolidating Concrete (SCC)

Self-Consolidating Concrete (SCC) is a highly flowable type of concrete that can fill formwork and encapsulate reinforcement without the need for mechanical vibration. This characteristic is achieved through the use of a higher proportion of fine aggregates and superplasticizers, which enhance its fluidity while maintaining stability and preventing segregation. SCC is particularly beneficial in complex formwork and congested reinforcement conditions, leading to increased construction efficiency and a superior surface finish with fewer defects like honeycombing. Its uniform consistency also improves performance in seismic regions, as it provides excellent lateral load response and overall structural integrity, making it a preferred choice for modern construction projects.

3.4.Fiber-Reinforced Concrete (FRC)

Fiber-Reinforced Concrete (FRC) incorporates fibrous materials—such as steel, glass, synthetic, or natural fibers—into the concrete mix to enhance its mechanical properties. This type of concrete significantly improves toughness, ductility, and crack resistance, making it particularly effective in applications where enhanced durability is essential. FRC exhibits better post-crack behavior, which helps maintain structural integrity under load and can reduce the propagation of cracks, thereby extending the lifespan of structures. Its benefits are especially valuable in seismic applications, as FRC can absorb energy and provide greater stability during lateral loads. While FRC can be more costly due to the additional materials, its performance advantages often justify the investment in demanding construction scenarios.

3.5.Precast Concrete

Precast concrete is a construction material that is cast and cured in a controlled environment before being transported to the construction site for assembly. This method allows for precise quality control, as the concrete is typically produced in a factory setting, ensuring uniformity and strength. Precast components, such as beams, columns, walls, and slabs, can be manufactured in a variety of shapes and sizes, enabling efficient construction and rapid installation. Additionally, precast concrete can enhance durability and reduce on-site construction time, minimizing labor costs and environmental impact. Its versatility and ability to be tailored for specific design requirements make precast concrete a popular choice in modern building projects, including commercial, residential, and infrastructural applications.

4.EFFECTS OF CONCRETE TYPE ON LATERAL RESPONSE

The type of concrete used in reinforced concrete (RC) frames significantly influences their lateral response, which is crucial in resisting lateral loads such as seismic and wind forces. Normal-strength concrete (NSC) provides basic load-bearing capacity but may lack the ductility needed for high seismic performance. High-strength concrete (HSC), while offering enhanced stiffness and load-bearing capacity, can be brittle, which may limit its effectiveness under extreme lateral displacements. Self-consolidating concrete (SCC) improves construction efficiency and structural homogeneity, which can positively impact lateral load distribution, though it may have limited ductility. Fiber-reinforced concrete (FRC) incorporates fibers that improve crack resistance and toughness, contributing to enhanced post-yield performance and energy dissipation during lateral loading. Overall, selecting the right concrete type involves balancing strength, ductility, and stiffness to meet the specific lateral load requirements of the structure.

5.LITERATURE REVIEW

In this section of the literature review, we have studied the previous research papers based on the different types of concrete on the Frame structure, and summary of previous papers has been given below:

Ahmed et al.(2023): The staged analysis (SA) yields higher bending moments and shearing forces compared to ordinary analysis (OA). The rigid frame (RF) system provides the minimum difference in differential displacement between OA and SA. SA and OA compared for concrete buildings' lateral load resistance. RF system showed minimum differences in displacements and internal forces.

Ying et al.(2023): Improved planar frame models considering system-level interactions. Reduced errors in peak overturning moments with updated models. System-level shake-table test of two-story low-damage concrete wall building. Modified planar frame models improve accuracy by considering system-level interactions.

Khalil et al.(2023): Axial load affects dynamic response and crack formation. Thicker CFRP layers improve impact resistance significantly. Investigated axial load's impact on RC members' dynamic response. Found axial compression affects inclined crack formation and damage severity.

Fajar et al.(2023): Infill walls significantly improve lateral strength of RC frames. Further research should consider infills as important components. Infill walls significantly improve lateral strength of RC frames. Further research needed on infill's role in seismic design.

Airong et al.(2023): Impact mass and velocity influence dynamic strain response. Longitudinal reinforcement ratio reduces plastic deformation and impact damage. RCCs tested under lateral impact loading through experiments and simulations. Impact mass and velocity positively correlated with extreme dynamic strain.

Chunfeng (2023): ECC frames have higher energy absorbing capacity and ductility compared to SCC/UHPC frames. ECC/UHPC frames have higher load carrying capacity compared to SCC frames. Describes performance of HPC frames under lateral loading. ECC frames show higher energy absorption and load capacity.

Xianhui et al.(2023): Composite columns have better impact resistance than RC columns. Outer steel tube is main energy dissipation component in columns. Study on impact responses of RC and composite columns. Composite columns show better overall impact resistance than RC columns.

Algamati et al.(2023): 3D software is more accurate than 2D software for seismic analysis. The applied cases do not exceed the limit of the NBCC 2015 Code. Investigating seismic behavior of concrete moment-resisting frame buildings. Analyzing seismic responses of 6- and 12-story reinforced concrete buildings.

Sila & Avgin (2022): Predicts behavior of poorly detailed RC columns under lateral loads. SAP2000 effectively models monotonic and hysteretic responses. Models monotonic and hysteretic behavior of RC columns under lateral loads. SAP2000 effectively predicts deformation compared to experimental results.

Abdullah et al.(2022): Experimental and numerical study on CFST columns' impact behavior. Four concrete types tested: NC, RuC, SFC, hybrid RuC-SFC.Twelve specimens tested under lateral impact loading conditions. High-speed camera measured mid-span deflection over time. Steel tubular showed plastic deformation and cracking under impact. Hybrid RuC-SFC had highest crack resistance; NC had lowest. Numerical results agreed with experimental findings.

Ion et al.(2022): Fragile global mechanism of failure by brittle rupture of RC columns in marginal end areas. "Strong Columns-Weak Beams" (SCWB) global ductile mechanism does not occur. Examines seismic response of MR RC frame structures. Proposes plastic hinge concentration in marginal beam areas.Reduces negative effects on beam-column joints. Observes participation of all lateral elements in energy dissipation.Validates innovative improvements for seismic response.

Tunc et al.(2022): High ductile frame models showed better lateral load carrying performances. Existence of structural steel in a column improved lateral load carrying capacity. 12 frame models with reinforced concrete encased steel composite columns were analyzed. High ductility frame models showed better lateral load carrying performances.

Maidiawati & Jafril (2021): Masonry infills increase lateral strength and stiffness of RC frames. Masonry infills decrease ductility performance of RC frames. Seismic responses of masonry infilled RC frames tested under lateral load.Full and partial infills increase strength, decrease ductility.

Siva et al.(2021): RC frames with stiffness irregularity are more vulnerable than those with shear wall/bracings. RC frames with shear wall have reduced seismic impact more than bracings. Seismic performance of stiffness irregular structures studied using response spectrum method. RC frames with shear wall have reduced seismic impact more than bracings.

Sae et al.(2020): The proposed frame model accurately captures the response of flexure-shear critical columns. The force-based formulation is computationally efficient compared to displacement-based models. Proposes a frame model for nonlinear analysis of RC columns. Validates efficiency through correlation with experimental responses under cyclic loadings.

Rohit & Kolurkar (2020): The number of bays in SMRF buildings significantly affects their stability. SMRF buildings with strong infill have higher base shear capacity than those with weak infill. Study compares performance of SMRF and OMRF buildings. Pushover analysis in SAP2000 to analyze structural behavior.

Davda et al.(2019): The study assessed the effects of irregularities in an asymmetric RCC building. Different models were prepared and analyzed using ETABS software. Study on irregularities in RCC building subjected to earthquake motions. Assessment using ETABS software with time history method analysis.

Senthil et al.(2018): Maximum resistance with cement mortar at 10 mm thickness. Cork and foam effective at 6 mm thickness. Studied interface thickness effects on infilled frames under lateral loads. Maximum resistance found with 10 mm cement mortar interface.

6.CONCLUSION

The review shows that advanced analysis and materials improve RC frames' lateral performance. Staged analysis (SA) predicts higher forces than ordinary analysis (OA), especially in rigid frames (Ahmed et al., 2023). Including system interactions reduces errors in overturning moments (Ying et al., 2023). Thicker CFRP layers enhance impact resistance (Khalil et al., 2023), and infill walls significantly strengthen frames (Fajar et al., 2023). ECC materials improve energy absorption (Chunfeng, 2023), and composite columns with steel tubes increase impact resistance (Xianhui et al., 2023). Seismic studies validate 3D modeling for precision (Algamati et al., 2023) and highlight structural adjustments like "Strong Columns-Weak Beams" for resilience (Ion et al., 2022). In short, refined methods and materials enhance RC frame stability under lateral and seismic loads.

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