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Numerical investigation of Slabs

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Abstract: *This study investigated the flexural performance of high-strength concrete (HSC) one-way reinforced concrete slabs reinforced with Basalt Fiber Reinforced Polymer (BFRP) bars. Both experimental testing and nonlinear finite element analysis (NLFEA) were conducted on seven BFRP-reinforced concrete slabs with dimensions of 700 × 1700 mm and thicknesses of 120 mm and 140 mm. The experimental results indicated that the ultimate flexural capacity and overall behavior of BFRP-reinforced slabs were improved compared to those with conventional steel reinforcement. The tensile strength of the BFRP bars was found to be approximately 2.5 times greater than the yield strength of steel reinforcement, and 1.79 times higher than the tensile strength of conventional bars. Structural performance observed in the experimental study was validated through finite element modeling using ANSYS. The correlation between experimental and numerical results showed a high level of agreement, with an average match of 89%, a coefficient of variance of 0.001, and a standard deviation of 0.03. The finite element analysis proved effective in predicting the nonlinear structural response of BFRP-reinforced concrete slabs.*

Key Word: *One way slab, HSC, BFRP, flexural behavior.*

I.INTRODUCTION

The structural performance and long-term durability of reinforced concrete (RC) members are fundamentally governed by the characteristics of the reinforcing materials. Although steel reinforcement has been traditionally used due to its high tensile strength, ductility, and bond compatibility with concrete, it is highly susceptible to corrosion, particularly in chloride-laden or aggressive chemical environments. Corrosion of steel not only compromises the structural integrity and serviceability of RC members but also significantly increases maintenance and life-cycle costs. Consequently, the search for durable, high-performance alternatives to steel reinforcement has led to the emergence of Fiber Reinforced Polymer (FRP) composites as a viable solution in civil infrastructure.

Among various types of FRPs, Basalt Fiber Reinforced Polymer (BFRP) bars have garnered increasing attention in recent years due to their superior mechanical properties and environmental sustainability. BFRP is manufactured from molten basalt rock through a controlled extrusion process, resulting in a reinforcement material that offers high tensile strength, excellent corrosion and chemical resistance, low electrical and thermal conductivity, and high fatigue durability. Unlike Glass or Carbon FRP, BFRP presents a cost-effective balance between mechanical performance and affordability, making it suitable for structural applications such as bridge decks, marine structures, and buildings in corrosive environments.

Parallel to the development of advanced reinforcement materials is the evolution of high-performance concrete mixtures**.** High-Strength Concrete (HSC), characterized by compressive strengths exceeding 55 MPa, exhibits enhanced compressive capacity, reduced permeability, improved abrasion resistance, and better dimensional stability. The integration of BFRP reinforcement with HSC can theoretically lead to high-performance composite members with significantly extended service lives and superior structural performance. However, the inherent brittleness and low modulus of elasticity of BFRP bars, when compared to steel, result in higher deflections, wider crack widths, and distinct failure modes, necessitating a thorough understanding of their structural implications—particularly under flexural loading conditions.

Flexural members, such as one-way reinforced concrete slabs, are especially sensitive to tension reinforcement characteristics. Since BFRP bars do not yield before failure but fail in a linear-elastic manner, their use in flexural applications demands a re-evaluation of existing design provisions and serviceability criteria. The primary concerns include crack initiation, crack propagation, stiffness degradation, and ultimate load-carrying capacity, which are critical in ensuring structural safety and service life. Thus, empirical research coupled with robust analytical modeling is essential to assess and predict the flexural behavior of BFRP-reinforced HSC slabs.

This study addresses this gap by conducting an integrated experimental and numerical investigation on the flexural performance of one-way HSC slabs reinforced with BFRP bars. Seven full-scale slab specimens, with plan dimensions of 700 mm × 1700 mm and thicknesses of 120 mm and 140 mm, were fabricated and subjected to four-point bending **tests** to capture key behavioral parameters such as first cracking load, ultimate load capacity, deflection response, and failure modes.

The test program was designed to isolate the effects of slab thickness and reinforcement configuration on overall performance.

To complement the experimental program, detailed nonlinear finite element analysis (NLFEA) was carried out using ANSYS 2024-R2. The numerical model incorporated key material nonlinearities, including concrete cracking, crushing, and tension stiffening**,** as well as bond-slip interactions between BFRP bars and concrete, to simulate realistic structural behavior. The models were calibrated and validated against the experimental results, with performance metrics including crack initiation load, peak load, mid-span deflection, and crack pattern distribution. The results demonstrated a high degree of correlation, with an average match of 89%, a coefficient of variance of 0.001, and a standard deviation of 0.0**3**, validating the reliability of the simulation framework.

The findings from this study contribute to the fundamental understanding of BFRP-reinforced HSC systems, offering insights into their design and analysis. Furthermore, the validated FE model provides a practical tool for predicting the flexural response of such slabs, supporting the advancement of performance-based design approaches in BFRP-reinforced concrete infrastructure.

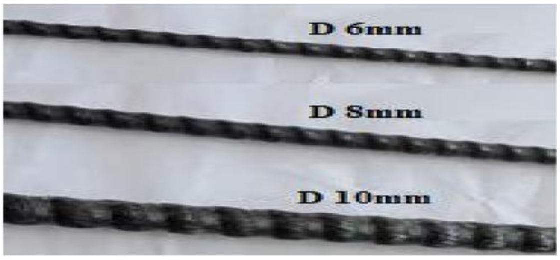

Fig.1 BFRP

II.RESULT AND DISCUSSION

The flexural performance of seven high-strength concrete (HSC) one-way slabs reinforced with Basalt Fiber Reinforced Polymer (BFRP) bars was evaluated through a combination of experimental testing and nonlinear finite element analysis (NLFEA).

Finite Element Model Correlation

Numerical simulations using ANSYS 2024-R2 exhibited strong agreement with experimental observations:

- First crack load, ultimate load, and deflection responses matched experimental results with an average accuracy of 89%**.**
- Coefficient of variance was calculated as 0.001, and standard deviation as 0.03, confirming model reliability.
- Simulated crack patterns and load paths aligned well with physical observations, validating the effectiveness of the NLFEA approach for modeling BFRP-reinforced systems.

III. CONCLUSION

The investigation confirmed that BFRP bars significantly enhance the flexural performance of high-strength concrete (HSC) one-way slabs. BFRP-reinforced slabs exhibited higher first cracking loads and ultimate load-carrying capacities—up to 25% greater than those with conventional steel reinforcement—due to the superior tensile strength of BFRP. Despite a lower modulus of elasticity, deflection behavior remained within acceptable limits, and failure occurred through concrete crushing, indicating a favorable structural response. The finite element analysis using ANSYS closely matched experimental results with an average correlation of 89%, validating its effectiveness in modeling nonlinear behavior. Overall, the study demonstrates that BFRP is a viable, durable alternative to steel in flexural applications, particularly in aggressive environmental conditions.

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