# COMPARATIVE STUDY ON THE STRUCTURAL BEHAVIOR OF CONCRETE COLUMNS REINFORCED WITH STEEL, GFRP, AND HYBRID REINFORCEMENT UNDER AXIAL LOADING

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**ABSTRACT -** This study presents a comparative experimental and numerical investigation on the axial load behavior of reinforced concrete (RC) columns with three reinforcement configurations: fully steel-reinforced, fully Glass Fibre Reinforced Polymer (GFRP)-reinforced, and hybrid-reinforced (steel longitudinal bars with GFRP stirrups). Three RC column specimens (235 mm × 235 mm × 1500 mm) were cast using M25 concrete and tested under monotonic axial compression. The steel-reinforced column achieved the highest axial capacity of 720 kN and exhibited excellent ductility. The GFRP-reinforced column supported 620 kN but failed in a brittle manner, although it demonstrated superior corrosion resistance. The hybrid column carried 670 kN, providing a balance of strength, ductility, and durability. Finite Element Analysis (FEA) using ABAQUS and the Concrete Damaged Plasticity (CDP) model was conducted to simulate structural performance. The numerical results closely matched experimental data, with a maximum deviation below 5%. The study highlights the effectiveness of GFRP and hybrid reinforcement systems as durable and practical alternatives to steel in aggressive environmental conditions, particularly for long-term structural applications.

## 1. INTRODUCTION

Reinforced concrete (RC) is widely used for its strength and versatility, but the corrosion of steel reinforcement remains a major durability concern, especially in coastal and industrial environments. Corrosion reduces load-carrying capacity, leads to concrete cracking and spalling, and shortens service life.

Glass Fibre Reinforced Polymer (GFRP) bars offer a corrosion-resistant alternative with high tensile strength and low weight. However, their low modulus of elasticity and brittle failure behavior limit their use in structural applications. Hybrid systems, combining steel and GFRP, aim to balance ductility and durability.

This study investigates the axial performance of RC columns with three reinforcement types: fully steel, fully GFRP, and hybrid (steel with GFRP stirrups). Experimental axial loading tests were conducted, supported by finite element modeling in ABAQUS using the Concrete Damaged Plasticity (CDP) model.

The results offer insights into the structural behavior and applicability of GFRP and hybrid reinforcement in aggressive environments.

### 1.1 LITERATURE REVIEW

**[1] Antonio De Luca et al. (2010):** The study investigated the axial performance of full-scale square concrete columns fully reinforced with Glass Fibre Reinforced Polymer (GFRP), including both longitudinal bars and stirrups, aiming to determine the suitability of GFRP as a replacement for steel reinforcement in compression members exposed to corrosive environments. Columns were subjected to pure axial loading, and the impact of varying tie spacing on confinement effectiveness was evaluated. Results confirmed that GFRP longitudinal bars provided adequate compressive strength for axial loads, while GFRP stirrups contributed significantly to confinement, enhancing ductility and controlling lateral deformation. Columns with closely spaced ties exhibited better performance and delayed failure, and overall, the axial behavior and failure modes of GFRP-reinforced columns were comparable to those of conventional steel-reinforced columns.

**[2] Hany Tobbi et al. (2012):** This experimental study examined the behavior of square concrete columns reinforced entirely with Glass Fibre Reinforced Polymer (GFRP) bars under concentric axial loading. The research focused on varying stirrup configurations, tie spacing, and concrete cover to assess their influence on column confinement and axial performance. Results demonstrated that GFRP-reinforced columns with closely spaced stirrups achieved higher axial strength and more stable failure modes. Effective confinement enhanced concrete integrity, delayed spalling, and increased load capacity. In many cases, GFRP-reinforced columns matched or exceeded the performance of steel reinforced columns. The study emphasized that proper stirrup detailing is essential for improving the ductility and structural reliability of GFRP-reinforced concrete columns.

**[3] Shakouri Mahmoudabadi et al. (2024):** This recent study investigated the behavior of GFRP-reinforced concrete columns subjected to eccentric axial loading, with a focus on the influence of stirrup spacing. Six square RC columns were tested under three levels of eccentricity and two stirrup spacing configurations to assess load capacity, failure modes, and confinement effectiveness. The results showed that higher eccentricity reduced axial strength and accelerated crack initiation, while tighter stirrup spacing enhanced confinement and delayed failure. Finite Element Analysis using ABAQUS closely matched the experimental results, confirming the validity of the modeling approach. The study highlighted the critical importance of accounting for eccentric loading effects in the structural design of GFRP RC columns.

### 1.2 GFRP Rebars

**Figure 1** illustrates the Glass Fibre Reinforced Polymer (GFRP) bars utilized in this study, which feature a **spiral-wrapped outer surface** designed to improve mechanical interlock and bond strength with the surrounding concrete. These bars are produced through a **hybrid process combining pultrusion and surface helical wrapping**, resulting in consistent geometry and high-performance properties suitable for structural applications.

**Technical Properties of GFRP Bars:**

- **Supplier**: ASLAN
- **Material Density**: 2100 kg/m³
- **Elastic Modulus**: 45 GPa
- **Tensile Strength (Ultimate)**: >750 MPa
- **Shear Strength (Ultimate)**: >150 MPa
- **Ultimate Strain Capacity**: Approx. 2.5%

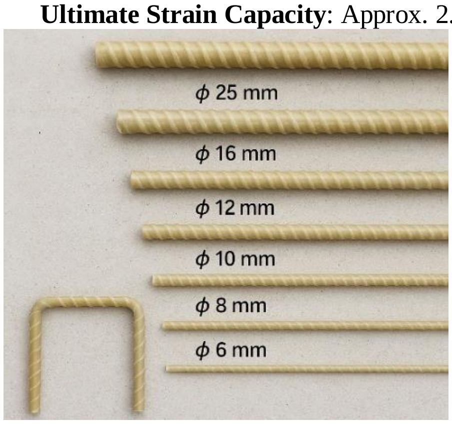


**Figure 1** GFRP Rebars

## 2. NUMERICAL MODELING USING ABAQUS SOFTWARE

ABAQUS is a powerful finite element analysis (FEA) tool capable of handling both static and dynamic problems with high accuracy. ABAQUS/CAE (Complete Abaqus Environment) is used for creating, assembling, analyzing, and visualizing models in a user-friendly interface. It supports complex geometries and provides an efficient platform for structural simulations. Additionally, ABAQUS/CFD extends the software's capabilities to computational fluid dynamics, allowing the simulation of fluid flow and heat transfer phenomena within the same environment. computational fluid dynamic capabilities with extensive support

### PROCESSING STAGE

**Pre-processing:**

In this phase, the geometry of the GFRP-reinforced concrete column was modeled, including the concrete core, longitudinal bars, and stirrups. Material properties were assigned based on experimental data, and mesh discretization was applied using appropriate element types. Boundary conditions and loading parameters were defined to replicate axial loading conditions.

**Simulation:**

The simulation was performed using ABAQUS/Standard, solving a nonlinear static analysis to capture the axial behavior of the column. Concrete damage plasticity was used to model the concrete response, while GFRP bars were modeled as linear elastic materials with brittle failure. The solver accounted for material nonlinearity and interaction between concrete and reinforcement.

**Post-processing:**

After the simulation, results such as load-displacement behavior, cracking patterns, stress distribution, and failure modes were visualized using the ABAQUS Visualization module. These outputs were used to assess the performance of GFRP-reinforced columns and compare with experimental findings for validation.

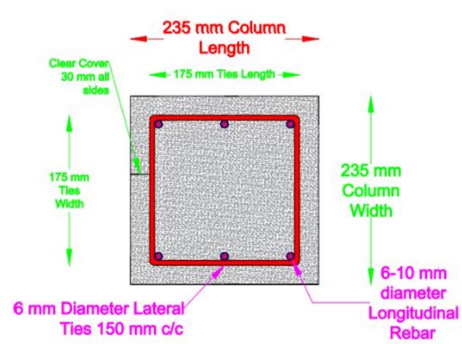


**Fig. 2 Plan View Of The Column Section.**

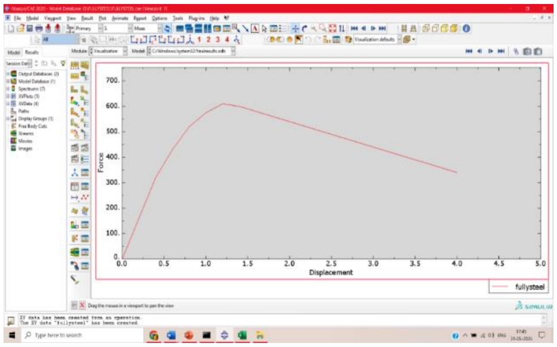


**Fig.3 Load Vs. Deflection Curve Of Fully Steel Reinforced Column**

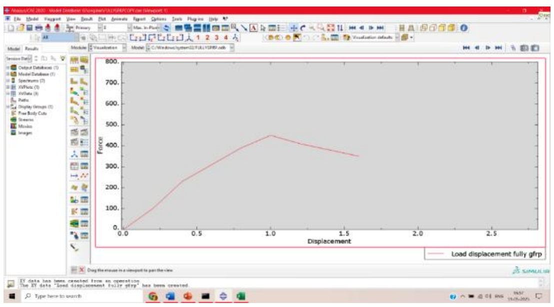


**Fig.4 Load Vs. Deflection Curve Of Fully GFRP Reinforced Column**

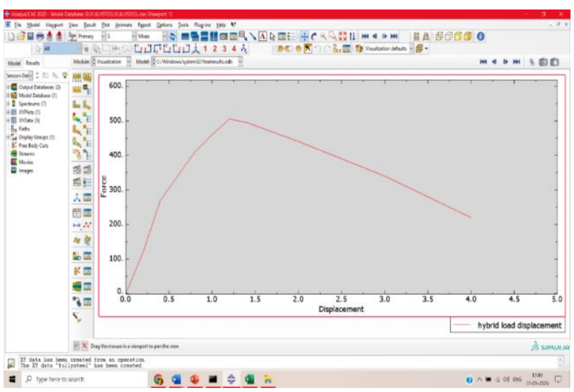


**Fig.5 Load Vs. Deflection Curve Of Hybrid Reinforced Column**

## 3. EXPERIMENTAL INVESTIGATION

**Preparation of Mould:**

A wooden mould with dimensions of 2000 mm × 225 mm × 300 mm was prepared. The inner surfaces were thoroughly cleaned and coated with shuttering oil to prevent bonding between the mould and concrete during demoulding.

**Mixing:**

Concrete was prepared using a mechanical mixer to achieve a uniform and consistent mix. Initially, the dry constituents were mixed thoroughly, followed by the gradual addition of water and chemical admixtures to attain the desired workability.

**Placing:**

The prepared concrete was placed into the mould in successive layers of approximately 100 mm thickness. Each layer was compacted using a mechanical needle vibrator to eliminate entrapped air and ensure proper bonding and uniformity throughout the specimen.


**Fig.6 Mixing Of Concrete**

**Fig.7 Curing Of Column Specimens.**

**Fig.8 Preparation Of Column Surface For Testing Using White Emulsion**

### 3.1 Column Cap

We use the column cap to ensure uniform load distribution during axial testing. It prevents localized crushing, minimizes stress concentrations at the column ends, and simulates ideal end conditions. The cap ensures the applied load is transferred evenly across the concrete surface, improving the accuracy and reliability of test results.

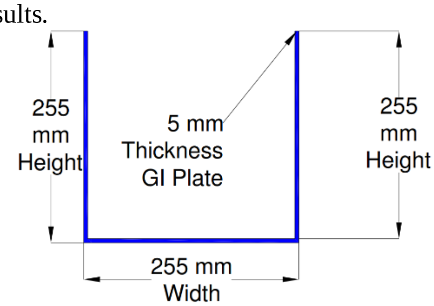


**Fig.9 Column Cap**

**Fig. 10 Fabricated Column Cap**

**Fig.11 Columns Test Setup**

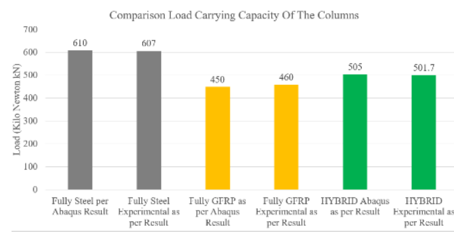


**Fig.12 Comparative Results Of All Columns In ABAQUS And Experimental Investigation For Load Carrying Capacity**

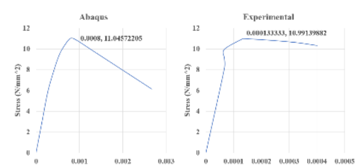


**Fig.13 Stress-Strain Curve Of Fully Steel Reinforced Column Results**

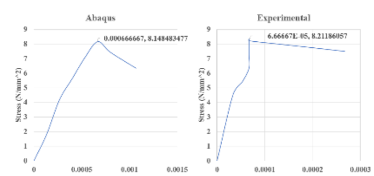


**Fig.14 Fig.13 Stress-Strain Curve Of Fully GFRP Reinforced Column Results**

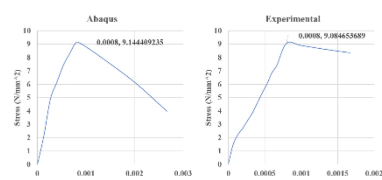


**Fig.15 Stress-Strain Curve Of HYBRID Reinforced Column Results**

## 5. CONCLUSIONS

1. The experimental and numerical (Abaqus) investigations clearly demonstrate that GFRP-reinforced concrete columns provide substantial advantages in terms of corrosion resistance and long-term durability compared to traditional steel-reinforced columns.

2. **Fully steel-reinforced columns** exhibited the highest initial strength and ductility, but are susceptible to corrosion in aggressive environments.

3. **GFRP-reinforced columns** showed comparable ultimate load capacity and excellent corrosion resistance, making them suitable for marine, coastal, and chemically aggressive conditions. However, they exhibited more brittle behavior with lower ductility.

4. **Hybrid columns** (steel longitudinal bars with GFRP stirrups) offered a balanced performance, combining the ductility and strength of steel with the durability benefits of GFRP. This configuration can be a practical solution for enhanced service life and structural reliability.

5. The Abaqus finite element models correlated well with experimental results, capturing the general load–deflection trends and peak loads, though some differences were noted due to modeling assumptions and real-world variabilities.

6. Future studies can investigate the performance under cyclic or seismic loads, and explore other reinforcement layouts including CFRP or basalt FRP

7. Overall, the study validates the use of GFRP and hybrid reinforcement as effective alternatives to steel, especially in environments prone to corrosion, and highlights the importance of proper modeling and material selection for optimal structural performance.

## 6. REFERENCES


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